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**AUTOMATED LOAD AND ASSEMBLY LINE FOR
LOOSE LOADED 105-MM TANK CARTRIDGES**

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MAY 1983



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DOVER, NEW JERSEY**

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Contractor Report ARLCD-CR-83012	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AUTOMATED LOAD AND ASSEMBLY LINE FOR LOOSE LOADED 105-mm TANK CARTRIDGES		5. TYPE OF REPORT & PERIOD COVERED Final Oct 1979 - May 1982
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kenneth P. Johnson, RISI Industries, Inc. K. Edward Lischick, Project Engineer, ARRADCOM		8. CONTRACT OR GRANT NUMBER(s) DAAK10-79-C-0405
9. PERFORMING ORGANIZATION NAME AND ADDRESS RISI Industries, Inc. 798 "F" Street Chula Vista, California 92010		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS MMT-5794064
11. CONTROLLING OFFICE NAME AND ADDRESS ARRADCOM, TSD STINFO Div (DRDAR-TSS) Dover, NJ 07801		12. REPORT DATE May 1983
		13. NUMBER OF PAGES 67
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office) ARRADCOM, LCWSL Energetic Systems Process Division (DRDAR-LCM-M) Dover, NJ 07801		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing techniques, processes, and equipment for use in production of Army materiel.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) 105-mm tank round Safe separation distance Liner assembly Automated production Line flow MMT-Ammunition Crimping assembly Labor saving Chamber gaging Cost reduction Primer assembly		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Army Ammunition Plants produce 105-mm tank rounds in uneconomical small runs with long lead times and high labor content. There is limited effort in improving the productivity of such lines. The present study was conducted to determine the feasibility of an automatic load and assembly production line. A complete system design concept was developed, fully substantiated through developmental engineering and, in part, reduced to a commercial technical data package.		

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SUMMARY

The objective of this project was to modernize the loading and assembly operations for a family of 105-mm tank cartridges by designing and developing a single automated processing line to increase production rates, improve item quality, reduce labor costs, shorten lead times, lower item cost, and amortize the equipment during peacetime.

In approaching the problem of designing equipment to modernize the load and assembly operations for loose-loaded 105-mm tank rounds, prime consideration was given to achieving a high productivity factor and a high rate of return on investment for the equipment. Productivity considerations required a high degree of automation and in-process inspection for the equipment. To reasonably amortize such sophisticated equipment with small peacetime production requirements necessitated that the equipment be capable of handling any one round of a family of loose-loaded tank rounds at any time.

The initial design studies indicated that the instantaneous conversion requirement for the proposed line would lead to excessive investment in what essentially would be standby equipment and would complicate the line's design. By redefining the product conversion requirement for the line as a zero time changeover capability of from one lot of ammunition to the following lot within the six types of rounds specified, a practical solution became feasible. For all intents and purposes, the line operator now has only to deal with two different rounds of ammunition at a time (i.e., those being loaded and assembled and those to be loaded and assembled). Duplication of equipment was now required only at the propellant loading station and at the projectile insertion station. Further simplification of the overall line was achieved through an analysis of the six different types of rounds with respect to component and process standardization. Numerous instances of optional common features and overlapping specifications were discovered and standardized where allowed by the respective product engineers. To enhance equipment reliability, such existing and successfully performing tooling which could be incorporated or adapted to automation was used in the design of the proposed line. Unprecedented tooling and mechanisms which could not be subjected to a rigorous engineering analysis were substantiated through mockup verification. Successful mockup demonstrations were carried out, particularly for the additive liner assembly stations and the projectile insertion mechanisms.

The general concept for the load and assembly line system consists of modules of automatically operating stations connected by a nonsynchronous pallet conveyor system. Specific and identified pallets move through this system, to be operated upon by the proper stations to produce any specific round. A 21 inch center-to-center pallet dimension was chosen to be consistent with a safe propagation distance and a practicable length and cycle time for the line. Subsequent live testing for safe propagation led to the incorporation of 3-inch diameter aluminum barrier rods on the pallets. The inclusion of these rods required considerable modification of station design to achieve rod clearance.

The following major station modules automatically perform the indicated load-and-assembly operations and their associated inspections:

1. Additive liner to cartridge case assembly
2. Primer to cartridge case assembly
3. Propellant metering and loading into cartridge case
4. Sealant application and projectile insertion into cartridge case
5. Cartridge case to projectile crimp
6. Cartridge assembly chamber gage
7. Cartridge assembly mark and accept/reject

Station operation, pallet flow, and part and round identification and disposition are all under the direct control of a remote central microprocessor. A companion microprocessor collects, processes, and displays various production and equipment status data. It also initiates, directs, and records equipment diagnostic and maintenance procedures. However, a manual jogging mode can be exercised for each station at the site for setup adjustment or repair conditions.

Consistent with the basic project task of providing a complete technical data package for the subsequent building and installation of the designed load and assembly line, the preparation of shop drawings, purchase and performance specifications, and equipment service manuals was started. However, because of insufficient funding, this effort was not completed to the same degree in all facets. By specific direction and contract amendment, that portion of the technical data package dealing with the additive liner to cartridge case assembly was required to be fully completed and documented. A preliminary hazard and RAM analysis of the complete system was completed.

The designed system, when implemented as prototype hardware, is expected to produce any of the six types of 105-mm tank rounds including the training rounds at the rate of 10 rounds per minute with a complement of ten attendants with zero changeover time. Under these conditions, it will save 48,000 man-hours over 1980 peacetime production conditions and will amortize a prototype line within 3 to 4 years with 1980 peacetime production requirements.

CONTENTS

	Page
Introduction	1
Background	1
Technical Approach	1
Design of 105-mm Tank Cartridge Load and Assembly System	2
Program Description	2
Technical Description of System Design	4
Technical Data Package	16
Mainline Conveyor Loop Operation and Flow	17
Description	17
Transfer 1	18
Transfer 2	18
Transfer 3	19
Transfer 4	20
Machine Stop	20
Assembly Line Flow Simulation of Mainline Conveyor	21
Hazard and Safety Analysis	21
General	21
Program Requirements	22
Economic Analysis	23
RAM Analysis of the 105-mm Load and Assembly System	25
Conclusions	26
Recommendations	26
Appendix - Safe Separation Distance Tests for 105 mm M456 HEAT-T Projectile	53
Distribution List	63

TABLES

		Page
1	Safe separation distance--summary of test results for 105 mm M456 HEAT-T projectile	27
2	105 mm M456 HEAT-T cartridge, shielded-vertical position	30
3	105 mm M456 HEAT-T cartridge, shielded-horizontal position	32
4	Summary of RAM requirements and predictions	34

FIGURES

1	Cartridge, 105 mm, APFSDS-T, XM735E2	35
2	Crimp configuration	36
3	Primer stake	37
4	105-mm tank cartridge load and assembly line	38
5	Mainline conveyor loop transfer location	39
6	Conveyor types	40
7	Transfer 1, device layout	41
8	Transfer 2, device layout	42
9	Transfer 3, device layout	43
10	Transfer 4, device layout	44
11	Machine centerline stop	45
12	105-mm assembly line	47
13	Operational line layout for the M456 HEAT-T projectile assembly line	49
14	Safe separation tests for 105 mm M456 HEAT-T projectile, unprotected	50
15	Safe separation tests for 105 mm M456 HEAT-T projectile, protected	51

INTRODUCTION

Background

Although tank ammunition is a major component in the weapon system, the load, assemble, and pack-out (LAP) operations have received relatively little attention in the DoD modernization program. This is partly due to the great diversity of tank ammunition which results in numerous but relatively small production runs. Each run is insufficient to justify economically the building of a modern and efficient production line. Consequently, the LAP of such tank ammunition has remained largely manual with the exception of the mechanization of selected operations. By contrast with other ammunition items, the production of a sophisticated and potentially high volume item such as the 105-mm tank ammunition has remained almost archaic. Such production methods contribute in part to the experienced unsatisfactory performance of the end item in use.

Through analysis of the diverse product, the similarity of design found was such that all items could be produced on a single line provided an effective and economically feasible system of tooling and feeding adaptability could be achieved. By consolidating the production of numerous models of cartridges on one LAP line, the high volume necessary for an economic justification is attained and an extraordinary potential for quality increase and cost decrease exists.

Although no specifically applicable work in the modernization of the LAP of tank ammunition had taken place, many new but related developments such as automatic propellant metering, automatic torque application and testing, use of programmable controllers, etc. have successfully occurred for other ammunition items. The availability of such a fund of precedent experience and knowledge will greatly reduce both the developmental risk and overall project costs for this proposed effort.

Technical Approach

The proposed technical approach must encompass a design philosophy which will consolidate the LAP processing of all the various individual model items on a single physical line. This design concept requirement will be met through the use of a common locating, holding, and turning fixture based on the commonality of the cartridge case and the majority of processing operations and through the use of interchangeable, programmable, controller actuated, duplicate-tooling, feeders and stations where product variability is required.

The very important parameters of high product quality and processing uniformity and control will be provided primarily through the detail engineering design and development of individual automatic processing and inspection stations for the required LAP operations. A concurrent result of this design approach will be the reduction of manual labor input. To further reduce the labor input through automation of material handling and to integrate the various stations into a centrally programmed and controlled system, a closed conveyor loop of circulating pallets on which the item holding fixtures are mounted is envisioned.

By incorporating into the proposed in-line LAP system periodic stations to eject pallets with defective components for rework and to reintroduce pallets with reworked or substitute components for continued processing, a very high level of overall line efficiency is achievable. The generation of scrap material will also be minimized.

In summary, the design of a single prototype LAP processing line for the various 105-mm tank ammunition was proposed. The line will have approximately 40 in-line stations where fixturized pallets carry the item components through the various phases of loading, assembling, packing, and inspecting at a nominal rate of 10 rounds per minute. Inspection rejects will be reworked and/or replaced within the system for continued processing. The end product of the line will be a fully assembled round packed in its individual shipping container. Developmental risk is expected to be very low because of design concepts based on precedent and demonstrated commercial and munitions technology.

Because of the inherent overall efficiencies and economics involved, the above proposal entailed a project for the turn-key installation of an automatic line for processing all load, assemble, and pack-out operations for the tank rounds. Due to fiscal constraints, however, only the execution of the design package for the load and assemble operations was implemented.

DESIGN OF 105-mm TANK CARTRIDGE LOAD AND ASSEMBLY SYSTEM

Program Description

RISI Industries, Inc. was chosen to carry out the actual task of developing and substantiating a design for an automated load and assembly system only and to deliver a complete technical data package suitable for the subsequent competitive solicitation for the building and installation of a prototype line at an army ammunition plant.

Contract requirements specified that an automated load and assembly line for a mix of 105-mm tank ammunition was to be designed with a net output of 10 rounds per minute and a 25% speedup capability. The rounds to be considered for assembly in this line were the M456A1E2, M490, M735, M735A1, XM797, and XM774 of the family of loose-loaded tank cartridges.

An exploded view of a typical, loose-loaded 105-mm tank cartridge is shown in figure 1.

The specific major operations to be automated comprised the following:

1. Feeding of cartridge case
2. Insertion of additive liner assembly ,
3. Inspection of liner to case assembly

4. Assembly of primer to case
5. Inspection of primer to case assembly
6. Metering of propellant charge
7. Loading of propellant charge into case
8. Application of projectile sealant
9. Insertion of projectile assembly into case
10. Crimping of case to projectile
11. Chamber gaging cartridge assembly
12. Marking cartridge assembly
13. Ejecting completed cartridge assembly

In the initial specification the automated line was required to have a capability to instantaneously convert from one type of ammunition to any of the other types specified. This requirement was imposed in the specification to maximize the on-line capability of the automated line. This capability would be vital to amortize the cost of the automated line under peacetime production requirements.

Early studies indicated that the instantaneous conversion capability would lead to excessive investment in essentially standby equipment and complicate the design of the facility beyond reason. ARRADCOM technical personnel agreed that a more practical objective would be to design into the automated line the capability to convert from one lot of ammunition to a different lot (among the six types of ammunition specified) with zero down time.

This change significantly reduced the complexity of the line operation and the need for standby equipment. For all practical purposes the line operator had only to deal with two different rounds of ammunition at a time: (1) the ammunition being loaded and assembled and (2) the next lot of ammunition to be loaded and assembled. Duplicate equipment was required at the propellant feed station and the projectile insertion station.

At the outset of the design effort, a literature search indicated that the safe propagation distance for these rounds is 15 inches. As a result, a separation distance of 21 inches between rounds was established for movement of rounds as they progressed from the propellant fill operation through the marker. Propagation tests were subsequently carried out (midway through the design effort) which indicated that propagation bars were required between assembled rounds. Rounds did not propagate at the specified separation distance, but excessive shrapnel penetration was observed. Propagation bars (two aluminum rods 3 inches in diameter and 30 inches tall) were then added to the pallets. This made it necessary to redesign most of the assembly stations on the line.

The approach that was used to design the automated assembly line was to use techniques and tooling which were being used at Milan Army Ammunition Plant (AAP). Improved tooling and standardization of components simplifying tooling requirements was completed.

To simplify the hardware of the line and to facilitate the assembly of the rounds, the following standardizing changes were made to the various individual rounds to be processed, as applicable:

1. The case crimp configuration is to be made the same for all involved rounds. A continuous 360-degree crimp is to be used and located in the same place on all rounds in accordance with figure 2. Proper bullet-pull values, also standardized, will be achieved through the setting of the crimping depth. This standardization will eliminate the need for two additional crimp stations in the design.

2. The sealant for the cartridge case to projectile joint is to be applied to the projectile 360-degree crimp groove rather than to the inside case wall. The modification will eliminate a separate sealant applicator station and is expected to produce a more uniform and consistent seal.

3. The configuration for the stake on the primer head is to be made the same for all rounds. The stake is to be made in such a manner as to displace metal into the slots in the primer (fig. 3). This standardization will simplify the tooling required in the automated assembly line.

Technical Description of System Design

The following discussion of the system design describing each assembly station and its status follows the flow of parts as they proceed through the assembly process. A three-dimensional representation of the proposed line is shown in figure 4.

Liner Insertion Station

This operation at Milan is completely manual and extremely labor intensive. Adhesive is applied to the liner by brush, the liner is rolled onto the forearm of the operator, and the operator inserts it into the cartridge case and then smooths into position. The operator checks the position with a marked stick and visually looks for bubbles or gaps between the liner and the wall of the cartridge case.

A program was carried out at RISI to model the critical components of the design concept which had been arrived at to insert the liner into the cartridge case. The sequence of operation of this concept is to (1) apply the adhesive to the inside of the cartridge case, (2) precondition the liner into a cylindrical shape before placing it in the cartridge case, (3) place the liner in the case, and (4) inspect the liner for position and condition after placement.

The mechanisms to accomplish this sequence of operations are mounted on a common table. Cartridge cases are moved in pairs from one operation to the next on a walking beam conveyor. Each operation is done by a pair of mechanisms which means that cartridge cases are moved as pairs by the walking beam conveyor in the normal mode. If any single mechanism is inoperable, the walking beam is programmed to move the cartridge cases one at a time. Production can then proceed at half rate while the inoperable mechanism is being replaced or repaired. Each mechanism in the liner insertion station is described in order of sequence.

Adhesive Applicator

The adhesive applicator is made up of an insertion arm mounted on Gilman slides, adhesive reservoir, metering device, and an optical scanner. The insertion arm, which carried three adhesive application rollers, is advanced into the cartridge case and lowered to allow contact between the rollers and the inside of the case. Adhesive is fed to the rollers as the case is rotated by an air motor and drive wheel. Adhesive flow is regulated by a positive shutoff valve located in the adhesive supply line coming from the pressurized adhesive reservoir. An optical inspection device monitors each roller applicator to assure that adhesive is deposited on the cartridge case. The adhesive applicator was modeled successfully.

Insertion Mechanism

The inserter mechanism includes the liner feed, liner conditioner, and insertion drum.

The liner feed is designed to deliver liners, one at a time, to the liner conditioner. Liners are placed in the feed mechanism which maintains a constant pressure on the singulator feed drum and can be replenished as the supply diminishes without stopping the singulator feed drum. The liner feed mechanism was not modeled.

The liner conditioner consists of three rubber faced rollers which preform the liner into a cylindrical shape before rolling the liner onto the insertion drum. The liner conditioner was modeled and proved to be very effective in forming the liner into the desired shape. Preconditioning the liner enhances the quality of the end product and does not produce any deleterious effects on the condition of the liner material.

The preformed liner is rolled tightly onto the insertion drum through 1 1/2 turns of wrap. The leading edge of the liner is securely held by retractable clamps and the trailing edge of the liner is securely confined under a shroud which encloses the upper part of the drum. In this configuration the liner is wrapped in a configuration small enough to clear the neck of the cartridge case. The liner and drum are inserted into the cartridge case and the case is then raised to contact the liner. The liner and cartridge case are rotated together in a clockwise direction until the trailing edge of the liner contacts

the cartridge case wall. The liner and cartridge case are then stopped and rotated together in a counterclockwise direction. The liner is unrolled from the insertion drum and placed and pressed in contact with the inside of the cartridge case during this counterclockwise rotation. The clamps on the leading edge of the liner are released and retracted into the drum during this last counterclockwise roll. This insertion process has been successfully modeled in sequence with the adhesive applicator step.

Liner Inspection

The liner is automatically inspected after insertion into the case at an inspection station which is separated from the inserter mechanism. The walking beam conveyor moves cartridge cases in pairs to the inspection station. The inspection arm which carries an optical pickup (Scanamatic) and a stationary hinged blade is inserted into the cartridge case and raised to bring the top of the hinged blade close to the liner. The cartridge case is then rotated. Any bulges in the liner will trip the blade. The optical device checks the location of the liner relative to the lip of the cartridge case. Location and liner conditions are both inspected.

The optical device was experimentally determined to be adequate to locate the liner position inside the case. This station was not modeled.

Reject Station

An automatic reject station is located along the walking beam downstream of the inspection station.

Controls

The design data package of the liner insertion station is complete in all details. The control system has been designed for this station on a stand-alone basis. Maintenance and jog mode control designs have been completed. An operational sequence has been provided so that a programmable controller can be incorporated for overall control.

Primer Insertion Station

After the liner has been inserted and glued inside the cartridge case, the next step in the assembly process is to assemble the primer and cartridge case. Two types of primers are used in 105-mm tank ammunition. Both types are screwed into place with an "O" ring seal under the head of the primer. After being torqued to a required level and checked for electrical continuity, the primers are staked.

During a trip to Milan AAP this operation was inspected. The "O" ring was placed on the primer by an operator as parts advanced on a moving conveyor. At Milan, the cartridge case and primer are hand started by the operator who then feeds the assembly to a rotary assembly machine.

It was decided to use a rotary assembly machine in this design and to automate the feeding of parts. This results in reducing the number of operators and removes personnel from a hazardous environment.

The rotary assembly machine was made up of the following nine stations on the table:

<u>Station</u>	<u>Description</u>
1 Cartridge case feed	Designed to singulate and feed cases, open end down, onto the rotary index table.
2 Primer feed	Designed to place the "O" ring on the primer, insert the primer into the cartridge case, and start the threads.
3 Primer feed	Designed as a mirror image of station 2. Set up alternate primer to feed the next lot with no down-time on the line.
4 Torque and height test	Torqued the primer into place and checked for height.
5 Continuity check	
6 Stake	Acceptable parts were staked.
7 Torque test	Reverse torque was applied to check the integrity of the stake.
8 Reject station	Bad parts are automatically ejected at this station.
9 Unload	Good parts were to be unloaded and placed on pallets, open side up, for transport through the rest of the assembly process.

The final design and details of the primer insertion station were completed. Drawings now require checking.

To meet the required rate it was necessary to include two primer insertion machines in the line. Line flow was divided into two parallel assembly sequences from the propellant scales through the chamber gage operation. Rounds were mounted vertically and moved on individual pallets on a nonsynchronous conveyor. Each pallet included two propagation bars and was designed to be positioned at each station by stops. The cartridge cases were mounted and restrained

on a spider in the middle of the pallet to make it convenient to lift the cartridge case off the pallet where this was required. The base of the cartridge case was restrained either by the pallet clamp or the station lifting device at all times.

The following is a list of conveyor types:

Main line conveyor - Double stranded accumulating chain

Return conveyor - Accumulating live roller

Reject conveyor - Accumulating live roller

Propellant Fill and Check Weigh

At this station the cartridge case is filled with the required weight of propellant. To meet the required line rate, it was determined that two scales operating in parallel would be required. To provide for lot changes, with zero downtime, it was determined that a second set of scales would also be required (four scales in all at this station).

The scale designs proposed by all three scale companies contacted incorporated a volumetric dump followed by a vibratory trickle feed to trim the charge to the proper weight. They all proposed use of a strain gage operating through an intrinsically safe circuit. The chute, through which the propellant was loaded into the cartridge case, was set to dump into a bypass hopper and only moved into position to fill the cartridge case after an accept signal was received.

The pallet carrying the cartridge case was located in the station by stops. The cartridge case was lifted off the pallet by a lifting device which included a strain gage that was to be the final check to ensure that propellant had been loaded into the cartridge case. The cartridge case was lifted to a point where the funnel from the scale was inside the lip before filling.

The interface design of the scale and material handling system was completed. Preliminary designs and proposals were received from three scale companies, Toledo, High Speed, and the Franklin Electric Company. Based on both cost and design considerations, the Franklin Electric Company was selected as the preferred scale vendor. The mechanical bulk feed was the cleanest design of the three and their price was 40% of the nearest competitor.

After filling, the cartridge case was lowered back onto the pallet and, with the lift retracted, the pallet was released to proceed to the projectile insertion station.

Projectile Insertion Station

At this station a sealant is applied to the projectile and the projectile is then inserted into the cartridge case. To meet the required line rate, it was experimentally determined that two insertion stations operating in parallel would be required. To provide for lot change, with zero downtime, it was determined that a second set of insertion stations would also be required (four insertion machines in all). Each includes a projectile feed conveyor, a cartridge case vibrator stand, and a device to transfer and feed projectiles from the projectile feed conveyor to the cartridge case.

During a visit to Milan AAP the operation of inserting the projectile into the cartridge case was observed. The fins of the projectile extend down into the volume occupied by propellant. The projectile is placed by hand into the cartridge case and rests on top of the propellant. The cartridge case is then oscillated around its centerline at a frequency which fluidizes the propellant, allowing the projectile to settle into the cartridge case of its own weight. No downward force, other than the weight of the projectile, is applied. The vibrating stand at Milan is made up of a plate with a clamp to hold the bottom portion of the cartridge case. The plate is oscillated by an air cylinder. Operating personnel at Milan indicated that it was necessary to adjust the frequency of the oscillator at frequent intervals.

The design of the oscillator could be improved significantly by using an electric motor drive operating through a clutch and connecting the clutch to the oscillating shaft through a simple crank link. This imposed simple harmonic motion on the oscillating shaft and permitted frequency adjustment by controlling motor speed. A commercially available clutch was chosen which was rated for four years life. A flywheel was added to prevent significant speed variations. In this arrangement the drive motor is on constantly.

To verify cycle time and demonstrate the adequacy of the design, a full scale mockup of the oscillator was constructed and tested. This mockup included the drive motor, clutch, flywheel, and oscillating shaft. Tests were conducted, using inert propellant which confirmed that the design concept was satisfactory and that line rate would be met. The projectile would settle more rapidly if the cartridge case and propellant were preconditioned by a brief vibration cycle before placing the projectile in the case. No downward force was applied to the projectile other than its own weight and the average insertion time was 6 seconds from the initiation of vibration.

At Milan the sealant is applied to the inside lip of the cartridge case before inserting the projectile. This has the effect of wiping the sealant away from the joint as the projectile is inserted into the cartridge case.

Placing a bead of sealant in the projectile crimp groove before inserting the projectile into the cartridge case was determined to be a better method of sealant application and one which would improve the integrity of the joint. This method was incorporated into the station design.

Projectile Feed Conveyor

The nonsynchronous projectile feed conveyor serves the function of transporting projectiles in a nose-up attitude from a feed station to the point where the transfer device picks up the projectile. At the feed station projectiles are placed by hand on individual pallets. The pallets carry the projectiles on a cylindrical carrier which engages the bottom edge of the obturator band. Projectile pallets are queued at the load and unload positions on the feed conveyor. This conveyor can be configured to turn corners and arrange to fit into virtually any building configuration required.

Projectile Feed Device

The projectile feed device serves the function of removing the projectile from the feed conveyor, applying sealant to the crimp groove, and placing the projectile into the cartridge case. This feeding device is mounted on a center column which carries two pickup clamps. Each pickup clamp is mounted on the end of a crossarm which swivels through 180 degrees on top of the center column. The center column telescopes to raise and lower the crossarm pickup assembly.

When the pickup assembly is lowered, one clamp is engaging a projectile on the feed conveyor while the other clamp is lowering another projectile into a cartridge case. When the pickup assembly is raised, one clamp is picking a projectile off the feed conveyor and the other has been opened to leave the other projectile in the cartridge case. The crossarm is then rotated through 180 degrees to repeat the cycle. During the 180-degree rotation, the projectile being transported is rotated on its own axis through 360 degrees and sealant is applied to the crimp groove in the projectile.

The projectile clamp has been designed to engage the projectile under the bottom lip of its obturator ring. This precludes dropping the projectile when the clamp is closed. The clamp is normally closed in the event of a power failure.

Cartridge Case Oscillator

The function of the oscillator is to fluidize the propellant in the cartridge case after the projectile has been set in place. This permits the projectile to settle into place with the projectile fins immersed in the propellant. The mechanics of the drive on the oscillator have already been described.

The cartridge case mounted on a pallet is located in this station by stops on the mainline conveyor. All stations on the line operate on demand (i.e., when a part is in position the station cycle begins).

The cartridge case is lifted vertically off the pallet by a lifting column which comes up directly below and through the pallet. The clamp on the lifting column is engaged on the bottom of the cartridge case before the pallet clamp is released. The lifting column shaft is an extension of the oscillating shaft. When the cartridge case has been lifted clear of the pallet and the projectile set in place, the cartridge case is oscillated to allow the projectile to settle into the case.

After the oscillating cycle is completed, the lifting column is lowered to return the cartridge case and projectile assembly to the pallet. The pallet is then advanced by the mainline conveyor to the crimping station.

The final design, including 90% of required details, was completed.

Crimping Station

The function of the crimp station is to crimp the cartridge case to the projectile. The specified crimp varied from one type of ammunition to another. The kinetic energy rounds used a 360-degree crimp and the shaped charge round varied from stab crimps to interrupted crimps. All types had a 360-degree crimp groove in the projectile body.

Because the crimp tooling is inherently massive, it would be extremely difficult to change this tooling to accommodate different crimp configurations as specified. It was, therefore, recommended that a 360-degree crimp be employed on all rounds. This was accepted by ARRADCOM and the tooling was designed accordingly. The 360-degree crimp tooling design is based on the tooling employed at Milan AAP to crimp kinetic energy rounds.

During a visit to Milan AAP the 360-degree crimp tooling employed on the kinetic energy rounds was examined and operating problems discussed with plant personnel. The crimp die used at Milan is an eight-segment die with each segment actuated by a separate hydraulic cylinder. Personnel at Milan indicated that they had some problems with this arrangement initially because all segments of the die could not close simultaneously. They solved this problem by reducing the travel of the die segments as much as possible. The tooling now appeared to perform well and left no discernable tool marks.

It was decided to use this practical experience; therefore, the shape of the die was copied in this design. An eight-segment die design is configured as the Milan tooling is used. The die is actuated from one hydraulic cylinder vertically oriented over the die segments. The hydraulic cylinder pushes on a cam plate which actuates all the die segments together. This arrangement ensures that all of the die segments will close at the same rate. Crimping can be done to pressure or limited by an adjustable stop on the cam plate.

At Milan, a hose clamp is in place on the SABOT of the kinetic energy round when the crimping operation takes place. ARRADCOM personnel agreed that the hose clamp would be removed before feeding these projectiles to the automated assembly line. A padded clamp was added to the crimp tooling to hold the SABOT of the kinetic energy round firmly during the crimping operation.

The operating sequence at this station is as follows: A pallet is positioned by stops on the mainline conveyor under the crimping tool. The round is raised vertically off the pallet by a lifting column which comes up directly below and through the pallet. The clamp on the lift is engaged on the bottom of the cartridge case before the pallet clamp is released. The round is raised into the crimp tool to the proper elevation and the crimping tool is then actuated. After crimping, the round is placed back on the pallet and the pallet is released to proceed to the chamber gage station. To meet line rate, two crimping stations operating in parallel are required.

The final design, including details of the crimp station, was completed.

Chamber Gage

The function of the chamber gage station is to inspect the assembled round for concentricity and size by inserting the round into a gage which simulates the breech of the gun. Force to insert the round is limited by specification to 60 pounds.

In this station, the chamber gage, which is counterweighted, is mounted on a frame which straddles the mainline conveyor. The chamber gage is lowered over the round and stopped within 6 inches of the base of the cartridge case. The round is then raised off the pallet and inserted into the chamber gage by a lift coming up through the pallet. The position of the cartridge case base in the chamber gage is sensed by three optical sensors spaced 120 degrees apart, around the base of the chamber gage.

In all stations from the check-weigh scales through the chamber gage, the lift heights required have been limited. This was done in the interest of safety, maintainability (easy access to lift cylinders), and cost (no lift pits need be constructed).

If a round becomes stuck in the chamber gage, an air fitting has been provided on the top of the gage cavity. This will make it possible to push the round out rather than just pulling on it with the lift clamp. The force to be applied by the lift is limited by the specification.

The final design of the chamber gage was completed along with 60% of the details.

To meet the required line rate, the design provides two chamber-gage stations operating in parallel. After passing through the chamber gage station, the flow of pallets is combined into a single row on a nonsynchronous conveyor. A transfer mechanism picks the assembled round off the pallet and places it on the feed conveyor to the marker.

Reject rounds remain on the respective pallets and are shunted off to a reject or rework station. If a round is rejected at any station on this line (check-weigh scales through chamber gage), a pin on the pallet is raised which inhibits any further assembly operations on that round.

Empty pallets are returned by live roller conveyor to feed mechanism coming off the primer insertion machines.

Cartridge Marker

The function of the marker is to print the proper lot identification number and round type on the finished ammunition.

The markers in use at Milan AAP were examined during a visit to that facility. The KIWI Company that supplied these markers was contacted to provide a design for this automated line. After a protracted period KIWI was not interested. Apparently the volume of machines required (one) was not great enough to get their attention. RISI then decided to proceed with the design of the marker.

This marker design proved to be rather straightforward. The base of the machine is made up of a linear indexing conveyor. The finished rounds are placed horizontally into nests on the conveyor with each nest equipped with rollers. Propagation bars were mounted on the conveyor between rounds. The pitch of this conveyor is 15 inches between rounds of ammunition.

Two commercially available printing heads are mounted 15 inches apart over the indexing conveyor with only one operational at a time. The printing head which is not operational is set up manually for the next lot ammunition to come through the assembly line. The changeover of printing heads between lots is instantaneous and automatic.

The final design of the marker was completed with 50% of the details.

The operational printing head is lowered to contact each round as the conveyor is indexed and stopped. An air operated friction wheel rotates the assembled round in its nest on the conveyor. Finished rounds feed off the end of the indexing conveyor onto a rollout table.

Control System

The finished controls provided for the liner insert station were completed under this contract to operate this station on a stand-alone basis. Station control boxes which provide for operation in the maintenance mode have been completed. A sequence of operations also has been provided for the entire station which will make it possible to specify a programmable controller and write the program at a later date.¹

¹ This information is contained in RISI Industries Inc. Specification No. 9335757, 9335759, 9335761, and 9335763.

The following description covers the control system which was being designed for the entire automated assembly line.

105-mm Tank Cartridge Assembly Line

The control system consisted of a microcomputer based system located in the central control room which will be a nonexplosion proof area. The input-output section of the microcomputer will transmit data to and receive data from the input-output systems located locally at the individual machines and materials handling systems.

The microcomputer system consisted of the following three sections: A main single-board computer including the 80/85 CPU, 16 K bytes of dynamic RAM, 8 K bytes of EPROM, two 24 line parallel I/O ports and one RS232 serial interface port. The second section includes a memory expansion board that would give the system memory the capability to expand to 64 K bytes of EPROM. The third is a parallel multiplexed input-output system. This system consists of individual circuit boards complete with the multiplex circuitry and input-output devices installed in the explosion proof control stations at each machine. Two separate parallel-multiplex lines will be used, each being able to control up to 1024 input-output devices, giving the system the capability of handling up to 2048 input-output points. The remote system will address the 80/85 CPU in the single board computer via two 19 conductor cables that will provide bidirectional communication and interface directly to the two 24-line parallel I/O ports on the main computer.

System control programming as well as diagnostics and visual display data will be handled by the single-board computer and memory expansion board. Diagnostic information will be transmitted to a panel mounted CRT and line printer via the RS232 interface port on the computer.

Controls at the individual machines and material handling systems will be installed in explosion proof enclosures mounted near the machine being controlled. The local enclosures will include all pushbuttons, switches, and lamps required to operate the machine manually. A selector switch is included to switch the machine from automatic to manual operation. The local control enclosure will also include all equipment required for automatic (under computer control) operation. This includes input-output controls as well as the individual I/O system, relays, transformers, fuses, and motor starters as required. Each enclosure will have an explosion proof disconnect switch mounted next to it.

Wiring between the central control room and the local control stations will consist of a 19 conductor, shielded cable run in conduit and daisy chained to each local control station. Individual wiring will be run in rigid conduit from the local control station to the individual machine switches; photocells will meet all explosion proof requirements.

The computer system located in the central control room will be installed in a 19-inch relay rack type enclosure. The central control console in the control room will consist of slope front consoles and a CRT display terminal.

Two 19-inch relay rack enclosures will be installed behind the slope front consoles and will be visible to the operator. Television monitors (8 each) will be installed in the front of the racks for easy scanning by the operator while he is at the control console. Also included in the relay racks along with the computer and TV monitors will be an uninterruptable power supply. This unit will provide clean transient free power to the computers, and in the event of a power failure or brownout, the equipment will continue to provide 120 V, 60-Hz line voltage to the computers for a period of not less than two weeks. A second backup computer is provided and installed in the relay rack above the primary computer. This unit will take over the process control in the event of a failure in the primary computer. The control console will include a visual display of the system as well as a CRT diagnostics readout.

Each local control station will be equipped to control the associated machine or material handling system. A disconnect switch is provided to remove any individual system from the line for maintenance without affecting the operation of other machines.

A listing of approximate input-output points for the system is given below:

<u>Function</u>	<u>Inputs</u>	<u>Outputs</u>
Walking beam conveyor and rollout table	32	17
Transfer to rotary table	14	11
Transfer to mainline conveyors (2 ea)	22	18
Transfer conveyor (3 ea)	48	21
Dual head adhesive applicator	18	14
Dual head liner insertion	32	24
Dual head liner inspection	10	12
Rotary table (2 ea)	202	162
Weight station (4 ea)	32	8
Applying sealant and insert projectile (4 ea)	104	84
Crimp verify and mark (2 ea)	26	14
Chamber gage (2 ea)	28	14
Marking	19	15
Mainline conveyor	182	84

<u>Function</u>	<u>Inputs</u>	<u>Outputs</u>
Pallet return conveyor	6	5
Projectile delivery	80	36
Transfer mainline to marking stations	11	9
System air pressure	<u>10</u>	<u> </u>
Total I/O requirements (1,434)	876	548

Input signals from the machines and material handling system will include both limit switches, photoelectric controllers, pushbuttons and selector switches as required for control of the system. All control devices were either designed for explosion proof requirements or mounted in an explosion proof enclosure as in the case of the photoelectric controllers. Output devices consisted of electrically controlled air solenoids, motor starters, lamps, etc.

The process control system was designed for fail-safe operation. If a control device fails, it will fail in such a manner that the system being controlled will not present a safety hazard to either personnel or machinery. Also, the process control program was written to require that each device activated by an output signal (solenoid or motor starter) must move to the correct position and operate a limit switch or other sensor before the next sequence in the operation can start.

Technical Data Package

The design concepts developed for the 105-mm tank cartridge integrated, automatic load, and assembly line were reduced to specific layouts, shop drawings, purchasing, and operational specifications. However, the degree of completion of such documentation became a variable with funding priorities and ranged from near 100% completion for the additive liner assembly section of the system to less than 50% for the propellant metering equipment.²

² "105-mm Assembly Line Bill of Material," RISI Industries, Inc., Chula Vista, California.

MAINLINE CONVEYOR LOOP OPERATION AND FLOW

Description

The mainline conveyor loop (fig. 5) shows the flow of pallets. Empty pallets are released to transfer 1 and alternately are delivered to mainline 1 and mainline 2. Pallets stop at the load stations where shells from the previous operations are loaded onto the pallets. When both mainlines are running, pallets proceed down their mainline, stopping at the work stations. Finally, good shells are unloaded at the accept stations. Empty pallets and pallets containing reject shells from mainlines 1 and 2 merge on transfer 3. Empty pallets exit from transfer 3 onto the return conveyor while pallets containing reject shells exit at the reject conveyor and are manually unloaded at the reject unload station. Empty pallets are returned from the reject conveyor to the return conveyor under operator control.

In the event that one or more machines are down on one mainline and one or more machines of different types are down on the other mainline, it will still be possible to keep the line running at half rate by transferring from mainline 1 to mainline 2 or vice versa using transfer T2. The quantity of T2 type transfers will be determined after the reliability and maintainability analysis has been completed. When both lines are running all T2 type transfers will be deactivated. The numbering system used here for limit switches and other devices starts at 1 for each transfer or machine stop. Later when machine logic is developed the same numbering system will be used. A full number for a limit switch might be T3LS5. This would be limit switch 5 on transfer 3. This numbering system lends itself to faster maintenance operations after computer diagnosis of a device failure. As far as possible, devices are numbered in the order that they operate and not necessarily in their physical order. For example, where there is a lift and a stop associated with it, the stop will operate before the lift so the solenoid associated with the stop will have a lower number. Detented solenoid operated valves will have an A or B solenoid. Example of SOL2A and SOL2B are associated with the same detented valve.

Not all the limit switches are used for control, some are used for diagnostics and/or management control.

Wherever possible, latching circuits have not been used to facilitate restart after an emergency stop or power failure.

For jogging, transfers are treated as a complete machine. Jogging a transfer will cause a pallet to move through the transfer in the same manner as the auto mode. Removing the jog signal will cause the transfer to stop at that point. Solenoid operated valves will be accessibly mounted so that individual valves can be operated by screwdriver.

Spring reset solenoid operated valves are used when the fail-safe failed mode is in the reset position. Generally, stops are de-energized up, so that in the event of power failure, stops will raise preventing movement of pallets. Detented solenoid operated valves are used where the fail-safe failed mode is in

the last position that the valve was in before power failure is maintained. Generally, lift valves are detented so that in the case of power failure while a pallet is half on and half off a lift, the lift will not change position which might cause a pallet to tilt and possibly jam.

The following is a list of conveyor types:

- Mainline - Double stranded accumulating chain
- Transfer - Double stranded nonaccumulating chain
- Return - Accumulating live roller
- Reject - Accumulating live roller

Design parameters of mainline conveyor and transfer points are shown in figures 6 through 11.

Transfer 1

Pallets arrive at stop 1 on the return conveyor and are released to lift 1, one at a time, if no pallet is present at PP2 or PP3 and lift 1 is down. When a pallet reaches PP3 and no pallet present is detected by pallet photocell PPC1 or PP4 and lift 2 is up, lift 1 is caused to raise and the transfer conveyor moves the empty pallet towards mainline 1.

Alternate pallets exit the transfer to mainline 1 and 2. If a pallet is to exit on mainline 1, stop 2 is caused to raise and when the pallet reaches PP5, lift 2 is lowered by operating SOL4B, and the pallet exits on mainline 1.

If a pallet is to exit on mainline 2, stop 2 is caused to lower and the pallet crosses lift 2. When the pallet reaches PP7, lift 3 is lowered and the pallet exits on mainline 2.

If limit switch PP4 is actuated when lift 2 is not up or PP4 is operated when lift 3 is not up, then the transfer motor M1 is stopped. Since this is an anticrash circuit and is not expected to operate often, a clutch and brake is not required.

Transfer 2

Pallets can be transferred from mainline 1 to 2 or vice versa using the T2 type transfer. When both mainlines are running, all stops and both lifts will be down and pallets will flow through the transfer without being transferred. When T2 is transferring, pallets enter from one mainline only and exit to the other mainline. At no time in the transfer modes do pallets enter from both mainlines or exit to both mainlines. There is no merge or diverge.

When transferring from mainline 1 to 2, stops 2 and 3 are held up, and stop 4 is held down. If a pallet is detected by PP2 or PP3 and a second pallet is detected by PP1, then stop 1 is raised to provide separation. Pallets are released one at a time to lift 1 by stop 1 if no pallet is present at PP2 or PP3 and lift 1 is down. Pallets arriving at lift 1 are stopped by stop 2. When PP3 is actuated and no pallets are detected by PPC1 and PP7 and lift 2 is up, then lift 1 is raised and the pallet transfers. Lift 2 is held up except when a pallet is detected by PP8, at which time lift 2 lowers until the pallet has fully exited from lift 2.

Transferring from mainline 2 to 1 is accomplished in a similar manner.

Motor M1 is a reversible motor which is off when mainline 1 and 2 are both operating. M1 causes the transfer conveyor to move from mainline 1 to 2 when transferring from 1 to 2 and vice versa when transferring from 2 to 1.

Transfer 3

The transfer contains a stop and lift at the end of mainline 1 and 2. Pallets merge at lift 1 then continue to lift 3. Empty pallets exit to the return conveyor; however, if a reject shell is detected by shell photocell SPC1, the pallet and reject will continue then exit to the reject conveyor. The transfer has three motors. Motor M1 has a clutch and brake and conveys from mainline 2 to 1. Motor M2 has a clutch and brake and conveys from mainline 1 to the return conveyor. Motor M3 runs continuously and conveys from the return conveyor to the reject conveyor. Because of the possibility of frequent starts and stops in the merge and diverge requirement M1 and M2 are equipped with solenoid operated clutch and brake.

If a pallet is detected by PP2 or PP3 and a second pallet is detected by PP1, the stop 2 is raised to provide separation. Pallets are released one at a time to lift 2 by stop 2 if no pallet is present at PP2 or PP3 and lift 2 is down. When a pallet is detected by PP3 and no pallet is present at PPC1 or PP4, lift 2 will raise causing the pallet to transfer. When the pallet has cleared PP3, lift 2 will lower. When the pallet reaches PP4 it will continue across lift 1 if lift 1 is up and no pallet is present at PP7, PPC2, PPC3, or PP8. If the lift is down or a pallet is present at PP7, PP3, or PP8, motor M1 clutch will be disengaged and the brake will be applied. The pallet will wait until the conditions are all correct for continuing. Pallets arriving at stop 1 are released one at a time to lift 1 when no pallet is present at PP6, PP7, or PPC2 and lift 1 is down. If there is a pallet at PP5 and there is no pallet at PP7 or PPC2, lift 2 will be energized down. If there is a pallet at PP4 and no pallet at PP7 or PPC2, lift 2 will be energized up.

Pallets arriving at PP8 will continue onto lift 3 if there is no pallet at PP9, PP10, or PP11 and lift 3 is up. If any of these conditions are not met, motor M2 clutch will disengage and the brake will be applied. The pallet will wait until the conditions are all correct for continuing. Empty pallets arriving at PP9 will energize lift 3 down and exit to the return conveyor. If a reject shell is detected by shell photocell SPC1, lift 3 remains up until the pallet

reaches PP11 at which time lift 3 is energized down. If there are no pallets at PP9 or PP1 or if there is a pallet at PP10, lift 3 is energized up.

If mainline 2 is down and mainline 1 only is selected, stop 2 is de-energized up and motor M1 is off. Pallets arriving on mainline 1 transfer as described above.

If mainline 1 is down and mainline 2 only is selected, stop 1 is de-energized up and lift 1 is energized up and pallets arriving on mainline 2 transfer as described above.

Transfer 4

Pallets with reject shells arrive at stop 1. The operator removes the shell then presses a start pushbutton. If there is no pallet at PP2 or PP3 and lift 1 is down and no shell is detected by shell photocell SPC1, the pallet will be released to lift 1. If a shell is detected or the other conditions are not met, the pallet will not be released by stop 1 when the start switch is pressed. When a pallet is present at PP3 and no pallet is present at PP4 or pallet photocell PPC1, lift 1 will raise and the pallet will transfer. When the pallet reaches PP5, lift 1 will be energized down. If an empty pallet in the return conveyor reaches PP6 and there is no pallet at PPC1 or PP4, lift 1 will be energized down. If a pallet reaches PP6 and there is no pallet at PPC1 and lift 1 is down, the pallet will continue. If there is a pallet at PPC1 or lift 1 is up, stop 2 will be de-energized up and the pallet will wait until conditions are clear for the pallet to continue.

Motor M1 is off until lift 1 is up. An off delay of one minute is provided so that when the operator is servicing the reject line which has accumulated several rejects, if he removes rejects at a rate greater than one per minute, the motor will continue running until one minute after he has finished removing the rejects. The motor will not be plugged (stopped and started several times during a short interval causing overheating).

The choke warning LS11 is an on-delay limit switch. Pallets passing past LS11 do not cause any signal. If pallets back up to the limit switch and it remains energized, a warning is presented to an operator to service the reject line.

Machine Stop

A machine stop is provided at each work station on the mainline 1 and 2 conveyors. This provides that the shell centerline is coincident with the machine operating centerline. A code reader reads lot A or lot B and rejects flags on the pallet.

If a machine is servicing lot A and pallets arrive at stop 1, they are released one at a time to stop 2 when no pallet is present at PP2 or PP3. Stop 2

is normally up and is energized down when the machine has completed its operating cycle. A wrong lot or a reject flag will also energize stop 2 down.

ASSEMBLY LINE FLOW SIMULATION ON MAINLINE CONVEYOR³

Operation of the 105-mm assembly line based on the mainline conveyor design (fig. 12) was simulated on a Tektronic Model 4054 computer. Simulation was used as a design tool to optimize the system configuration and production capability and to verify the actual design.

The computer verified the design and gave data resulting from changes made to machine cycle time and system flow. All possible variations to input data were not attempted, but basic parameters were changed to examine possible resultant system operation. As the data indicated, system production may be varied by changing the walking beam cycle time. This can therefore be used to adjust production requirement. To use the system to its fullest, the system should remain in constant operation. This will minimize time to load and unload which subtracts directly from total production. Simulation also indicates that the machine stations can be bypassed on the mainline with negligible effect on the half-system rate. The minimum number of pallets to operate the system was found to be 56. As the system is physically lengthened, the number of pallets required also increases.

HAZARD AND SAFETY ANALYSIS

General

A concept and engineering risk and hazards analysis study program was performed on the automated load and assembly line. The objective of the preliminary hazard analysis completed was to determine the adequacy of the following design concepts with regard to safety characteristics.

1. an evaluation of the technical approaches to the safety of the design features
2. highlighting any special areas of safety consideration
3. the identification of possible safety interface problems.

The preliminary hazards analysis was conducted with AMCR 385-100, AMC Safety Manual dated 11 January 1977, ARMCOR 385-4 Hazards Analysis Report dated 21

³ "105-mm Assembly Line Computer Simulation Contract No. DAAK10-79-C-0405," RISI Industries, Inc., Chula Vista, California.

March 1975, and PBM OSM 385-1 Chapter 3, Change 1. The hazard category designations were assigned in accordance with MIL-STD-882A, System Safety.

Program Requirements

During the preliminary hazards analysis, each operating and failure mode in the system was listed with an associated estimated probability of a hazardous failure event. The corresponding hazard category was assigned in accordance with the MIL-STD-882A, System Safety Requirements. The analysis achieved the objectives of this phase of the study program by

1. Assessing the magnitude of potential hazards in the system
2. Identifying possible failure modes and hazard situations in order to formulate effective corrective actions
3. Ranking the hazard level of each operation

Approximately 82 failure modes were identified in the process system. These failure modes reflect preliminary estimates of the hazards which may occur in the operations. The specific results of the preliminary hazards analysis are detailed in the report furnished by Safety Consulting Engineers, Inc.⁴ For the most part these considerations were dealt with in the ensuing design effort and the hazards eliminated or contained.

In these considerations, the safe separation distance for live components became a special concern because of their effect on basic design parameters for the line. After a review of the operational line layout for the M456 HEAT-T cartridge (fig. 13), a total of five cartridge and subassembly configurations were considered in need of safe separation distance determination. These five configurations were (1) M83 primers contained within vertically oriented cartridge cases, (2) fully loaded and vertically oriented M148 cartridge cases, (3) vertically oriented M456 projectiles, (4) vertically oriented M456 cartridges, and (5) horizontally oriented M456 cartridges. A test plan was formulated for simulating loading plant operational conditions as shown in the appendix. However, the actual testing was further reduced to only three configurations as it was decided to use the nonpropagation distance determined for complete M456 cartridges for both the cartridge case and projectile spacing. This decision was felt to be a valid and safe alternative since it portrayed a worst-case condition. Instead of a complete safe separation test series for the primer-in-cartridge-case configuration, a series of five tests were conducted to determine if a functioning M83 primer would even damage the containing case. In all tests,

⁴ C. James Dahn and Robert J. Stanis, "Preliminary Hazard Analysis Report on the Design of an Automated Load-and-Assembly Production Line for 105-mm Tank Cartridges," Report No. 415801, Safety Consulting Engineers, Inc., Rosemont, Illinois, April 15, 1980.

the case was not even dented; therefore, it was felt there would be no chance of primer propagation between cases.

A summary of results for the 105-mm M456 HEAT-T projectile safe separation distance testing which was conducted at the National Space Technology Laboratory Station, Mississippi, is given in table 2. Before and after views of the unprotected and protected conditions of the receptor cartridge are shown in figures 14 and 15. Unprotected cartridges and projectiles, although not set off during testing, received such severe penetration damage that such an occurrence was considered only a matter of time. When protected with a shield of a 3-inch diameter aluminum bar (6061-T6), all receptors remained undamaged. Testing was carried out only to a centerline distance of 15 inches horizontal and 23 inches vertical since physical constraints on the line design distances made these dimensions practical limits.

A total of 52 confirmatory tests (26 double tests) were conducted on the M456 cartridge in a vertical orientation with 3-inch diameter aluminum shields for safe separation nonpropagation centerline distance of 23 inches. This provided an upper limit of 6.85% probability of propagation of an explosive incident at the 95% confidence level (table 2).

A total of 54 confirmatory tests (27 double tests) were conducted on the M456 cartridge in a horizontal orientation with 3-inch diameter aluminum shields for a safe separation nonpropagation centerline distance of 15 inches. This provided an upper limit of 6.60% probability of propagation of an explosive incident at the 95% confidence level (table 3).

ECONOMIC ANALYSIS⁵

The economic analysis (1980 Data Base) was carried out to assess the impact on operating costs which would result from automating a portion of the 105-mm LAP operation at Milan AAP. A comparison was made of the direct labor requirement in the existing hand line and the projected direct labor requirement in a partly automated LAP operation. The current program would automate only a portion of the LAP facility (i.e., liner insertion through cartridge marking).

The data relating to the current direct labor requirement in the X-14 building for assembly of the M735 cartridge was obtained from Milan LAP. A total of 31 people would be eliminated from the complete LAP facility through automation.

⁵ Economic analysis is based on 1980 dollars.

To operate the proposed automated section of the line, personnel will be required as follows:

1. One control room operator
2. One mechanic for a total of three in the building
3. Five operators, two to feed projectiles, two to provide supplies to the liner inserter and primer insert machines, and one to feed batches of cartridge cases

The net reduction in direct labor personnel required will, therefore, be 24 people.

The analysis was carried out based on a production rate requirement of 3,000,000 rounds per year. This is close to the average capacity of the automated line, operating on a three-shift basis. The annual savings based on the average fiscal year defense procurement (FYDP) requirements, projected over the next five years, is shown below:

Hand Line (Milan AAP)

Rate of production/line	385 units/hr
Available production minutes/shift	420 min
Direct labor required/line	71 people
Manhours/operator/year	2,000 hours
Cost/operator/year (no Oh'd)	20,000 dollars
Production requirement/year	3,000,000 units

Calculations for Hand Line

Line production/shift		
$385 \times 420/60$	=	2,695 units
Line production/year		
$2,695 \times 2,000/8$	=	673,750 units
No. of lines/annual requirement		
$3,000,000/673,750$	=	4.45 lines
Annual labor cost/line		
$71 \times 20,000$	=	1,420,000 dollars
Labor cost/total production		
$4.45 \times 1,420,000$	=	6,319,000 dollars/year

Partly Automated Line

Rate of production	10 cycles/min
Line average efficiency	90 percent
Available production minutes/shift	420 min

Direct labor required/line (71-24)	47 people
Manhours/operator/years	2,000 hours
Cost/operator/year (no Oh'd)	20,000 dollars
Production requirement/year	3,000,000 units

Calculations for Partly Automated Line

Line production/shift $420 \times 10 \times 0.9$	=	3,780 units
Line production/year $3,780 \times 2,000/8$	=	945,000 units
No. of lines/annual requirement $3,000,000/945,000$	=	3.17 lines
Annual labor cost/line $47 \times 20,000$	=	940,000 dollars
Labor cost/total production $3.17 \times 940,000$	=	2,979,800 dollars/yr

Annual Savings

$6,319,000 - 2,979,800$	=	3,339,200 dollars/yr
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Savings Per Unit

$3,339,200/3,000,000$	=	\$1.11 per round
Projected average annual FYDP requirement (5 years)	=	1,164,000 units/year
Annual FYDP savings $1.11 \times 1,164,000$	=	1,292,040 dollars/year

RAM ANALYSIS OF THE 105-mm LOAD AND ASSEMBLY SYSTEM

A preliminary reliability, availability, and maintainability (RAM) analysis of the total load and assembly line was completed (fig. 12). The RAM analysis report by Design and Evaluation, Inc.⁶ showed that the design of the 105-mm tank cartridge production line has the potential to exceed the specified mean-time-between-failures (MTBF) and availability (A) requirements while the predicted mean-time-to-repair (MTTR) falls below its requirement. However, it should be

⁶ "Reliability, Availability, and Maintainability Assessments and Analysis Report for the Preliminary Design of the 105-mm Tank Cartridge Production Line," RISI Industries, Inc., Chula Vista, California 92010.

noted that the design of the Electronic Control System will include the capability for automatic troubleshooting of all stations within the line. This was not considered in this preliminary analysis but will be as the design matures. This feature is expected to reduce the predicted MTTR significantly. A summary of the RAM requirements and present predictions is shown in table 4.

The MTBF and availability predictions are considered to be comfortable margins at this state of development. The complexity of the line is not expected to increase significantly enough to have a major degrading impact on the present RAM predictions.

CONCLUSIONS

The design objective--an automated, integrated load and assembly line capable of processing M456A1E2, M490, M735, M735A1, and M774 105-mm tank rounds at a rate of 10 rounds per minute in any sequence, with zero changeover time and greatly reduced personnel hazard exposure and unit item cost--was achieved with a concept that was fully developed and is specific and detailed. Areas of greatest technical risk were thoroughly substantiated through engineering analysis and testing with mockup hardware.

The contractually required delivery of a standard, finished technical data package, suitable for the competitive procurement of production hardware, was achieved to an estimated overall 70% level with the receipt of mylar shop drawings, material lists, purchase specifications, and the operation manuals. Sufficient funds to complete the remaining 30% of the technical data package were not available.

RECOMMENDATIONS

The gains in productivity and production economics inherent in the automated load and assembly line developed for the family of loose-loaded 105-mm tank rounds strongly recommend implementation as hardware, either as a complete system or in incremental sections.

Because of the extraordinary production difficulties experienced on current production lines with the additive liner-to-case assembly operations, the immediate building and installation of that section at a GOCO plant is also highly recommended.

Table 1. (cont)

SAFE SEPARATION DISTANCE

SUMMARY OF RESULTS FOR 105mm M 456 HEAT-T PROJECTILE (COMPLETE PROJECTILE POSITIONED VERTICALLY)												
TEST NUMBER	LEFT ACCEPTOR						RIGHT ACCEPTOR					
	DISTANCE FROM DONOR mm (INCH)		REMARKS	DISTANCE THROWN METERS (FEET)		DETONATION	DISTANCE FROM DONOR mm (INCH)		DETONATION	DISTANCE THROWN METERS (FEET)		REMARKS
	ACCEPTOR	BARRIER		ACCEPTOR	BARRIER		ACCEPTOR	BARRIER		ACCEPTOR	BARRIER	
33-80-C1 EXPLORATORY	584.2 (23)	NO BARRIER	Warhead separated from cartridge case, propellant burned, many penetrations in warhead	15.39 (50.5)	NO BARRIER	NO	457.2 (18)	NO BARRIER	NO	22.25 (73)	NO BARRIER	Warhead separated from cartridge case, propellant burned, many penetrations in warhead
33-80-C2 EXPLORATORY	914.4 (36)	NO BARRIER	Warhead separated from cartridge case, propellant burned, 1 penetration in warhead	23.17 (76)	NO BARRIER	NO	304.8 (12)	NO BARRIER	NO	17.38 (57)	NO BARRIER	Warhead separated from cartridge case, propellant burned, many penetrations in warhead, nose off
33-80-C3 EXPLORATORY	914.4 (36)	NO BARRIER	Warhead separated from cartridge case, propellant burned, 2 penetrations in warhead	8.08 (26.5)	NO BARRIER	NO	304.8 (12)	NO BARRIER	NO	13.56 (44.5)	NO BARRIER	Warhead separated from cartridge case, propellant burned, many penetrations in warhead
33-80-C4 EXPLORATORY	584.2 (23)	330.2 (13)	NO DAMAGE REUSEABLE	6.40 (21)	5.03 (16.5)	NO	584.2 (23)	254 (10)	NO	5.79 (19)	10.36 (34)	NO DAMAGE REUSEABLE
33-80-C5	584.2 (23)	254 (10)	NO DAMAGE REUSEABLE	4.57 (15)	10.06 (33)	NO	584.2 (23)	254 (10)	NO	6.40 (21)	8.23 (27)	NO DAMAGE REUSEABLE
33-80-C6	584.2 (23)	254 (10)	NO DAMAGE REUSEABLE	3.66 (12)	8.54 (28)	NO	584.2 (23)	254 (10)	NO	12.5 (41)	3.66 (12)	WARHEAD SEPARATED FROM CARTRIDGE CASE AT FIN NO OTHER DAMAGE
33-80-C7	584.2 (23)	254 (10)	NO DAMAGE REUSEABLE	10.06 (33)	6.4 (21)	NO	584.2 (23)	254 (10)	NO	8.54 (28)	10.06 (33)	NO DAMAGE REUSEABLE
33-80-C8	584.2 (23)	254 (10)	WARHEAD SEPARATED FROM CARTRIDGE CASE - NO OTHER DAMAGE	9.75 (32)	6.10 (20)	NO	584.2 (23)	254 (10)	NO	6.10 (20)	3.66 (12)	NO DAMAGE REUSEABLE
33-80-C9	584.2 (23)	254 (10)	NO DAMAGE REUSEABLE	6.40 (21)	6.40 (21)	NO	584.2 (23)	254 (10)	NO	7.62 (25)	4.57 (15)	NO DAMAGE REUSEABLE

SAFE SEPARATION DISTANCE

29

Table 2. 105 mm M456 HEAT-T cartridge, shielded-vertical position

Test	Distance				Remarks*
	Acceptor		Barrier		
	(cm)	(in.)	(cm)	(in.)	
1L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
2L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
3L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
4L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
5L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	No damage
6L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
7L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
8L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case
9L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
10L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
11L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	No damage
12L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case
13L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	No damage
14L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case

* No detonation propagation

Table 2. (cont)

Test	Distance				Remarks*
	Acceptor		Barrier		
	(cm)	(in.)	(cm)	(in.)	
15L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
16L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
17L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case
18L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	No damage
19L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case
20L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
21L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
22L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	Projectile separated from case
23L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	Projectile separated from case
24L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage
25L	58.4	23.0	25.4	10.0	Projectile separated from case
R	58.4	23.0	25.4	10.0	Projectile separated from case
26L	58.4	23.0	25.4	10.0	No damage
R	58.4	23.0	25.4	10.0	No damage

Table 3. 105 mm M456 HEAT-T cartridge, shielded-horizontal position

Test	Distance				Remarks*
	Acceptor		Barrier		
	(cm)	(in.)	(cm)	(in.)	
1L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
2L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
3L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
4L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	Projectile separated from case
5L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
6L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
7L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	Projectile separated from case
8L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
9L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
10L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
11L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	Projectile separated from case
12L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
13L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
14L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	Projectile separated from case

* No detonation propagation

Table 3. (cont)

Test	Distance				Remarks*
	Acceptor		Barrier		
	(cm)	(in.)	(cm)	(in.)	
15L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	Projectile separated from case
16L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
17L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
18L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
19L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	Projectile separated from case
20L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
21L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
22L	38.1	15.0	19.0	7.5	Projectile separated from case
R	38.1	15.0	19.0	7.5	No damage
23L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	Projectile separated from case
24L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
25L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
26L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	No damage
27L	38.1	15.0	19.0	7.5	No damage
R	38.1	15.0	19.0	7.5	Projectile separated from case

Table 4. Summary of RAM requirements and predictions

<u>RAM parameter</u>	<u>Requirement</u>	<u>Prediction</u>
Mean-time-between-failure (MTBF)	285 min (4.75 hr)	708 min (11.8 hr)
Mean-time-to-repair (MTTR)	15 min	23.08 min
Maximum repair time for 95% of system failures	3 hr	100% of system failures meet this requirement
Maximum time for all preventive maintenance tasks	5 hr	To be determined
Availability, Inherent (A_i)*	0.95%	0.9684%

$$* A_i = \frac{MTBF}{MTBF + MTTR}$$

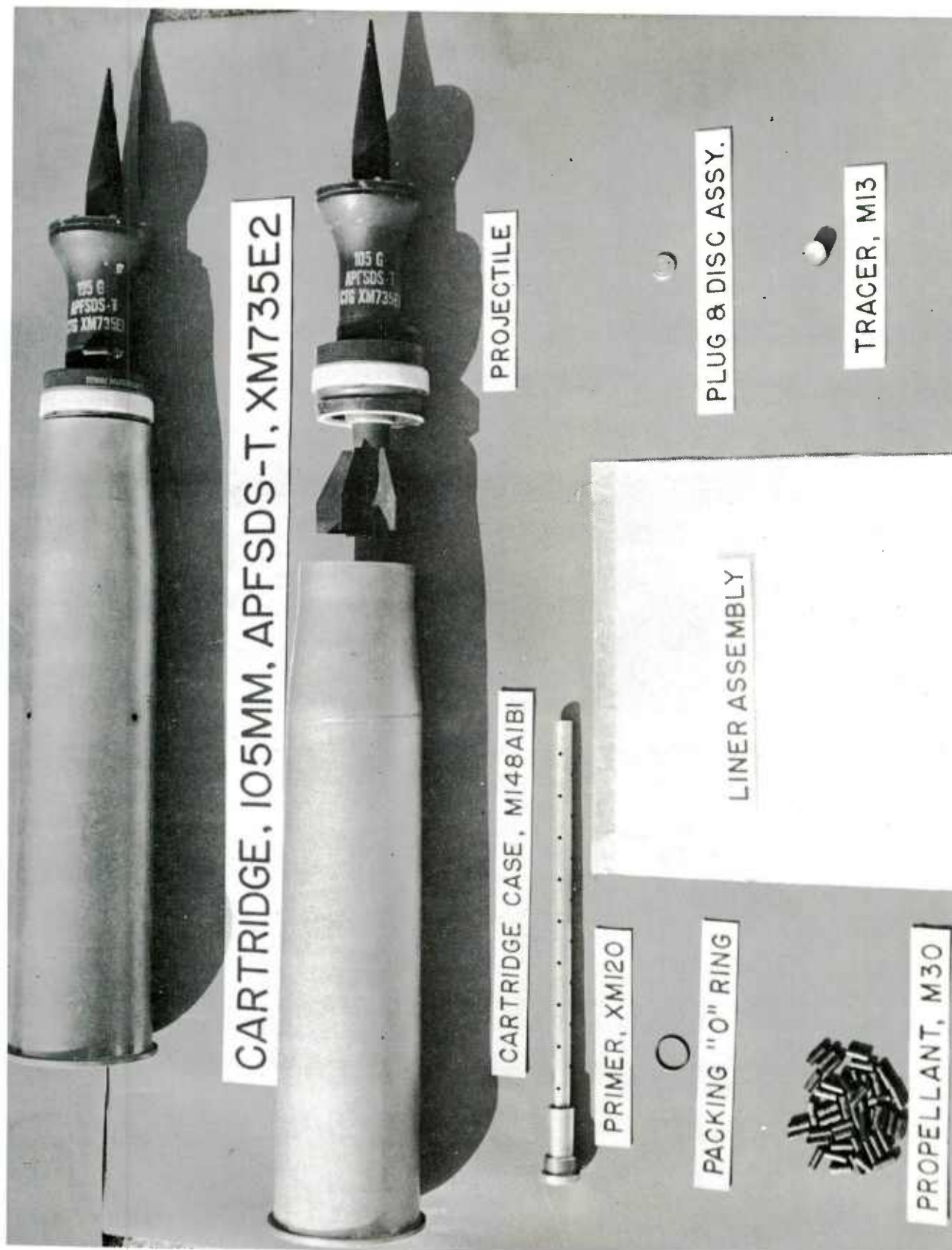
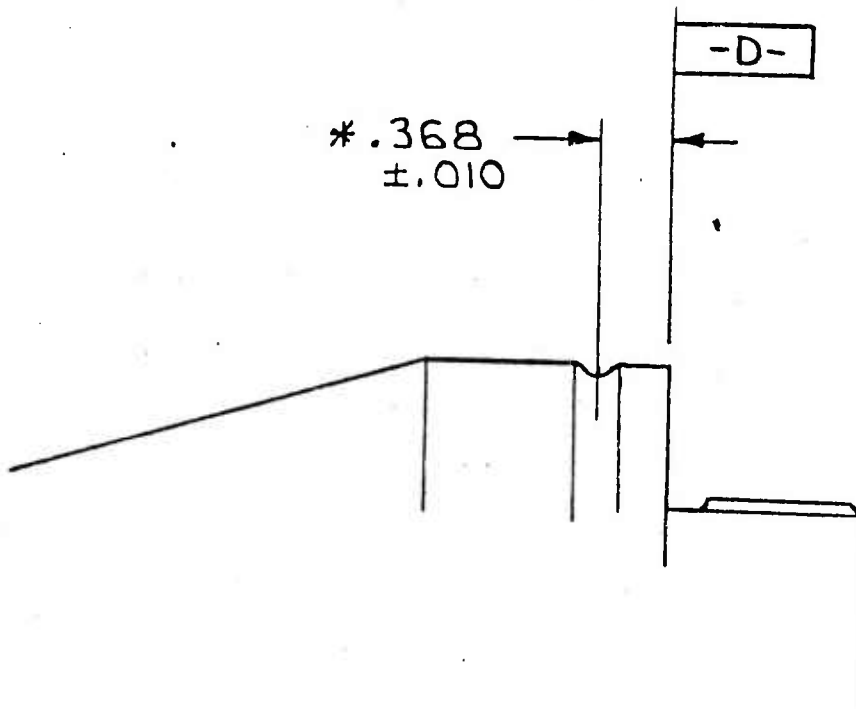


Figure 1. Cartridge, 105 mm, APFSDS-T, XM735E2

Retain base of obturator groove as datum. Move crimp groove to dimensions shown to correspond to position indicated on 9329516 drawing. Suggested dimensioning, see 10523474 for "is" condition.



Establish base of obturator groove as datum for locating crimp groove and sabot shoulder. Suggested dimensioning see 9329516 for "is" condition.

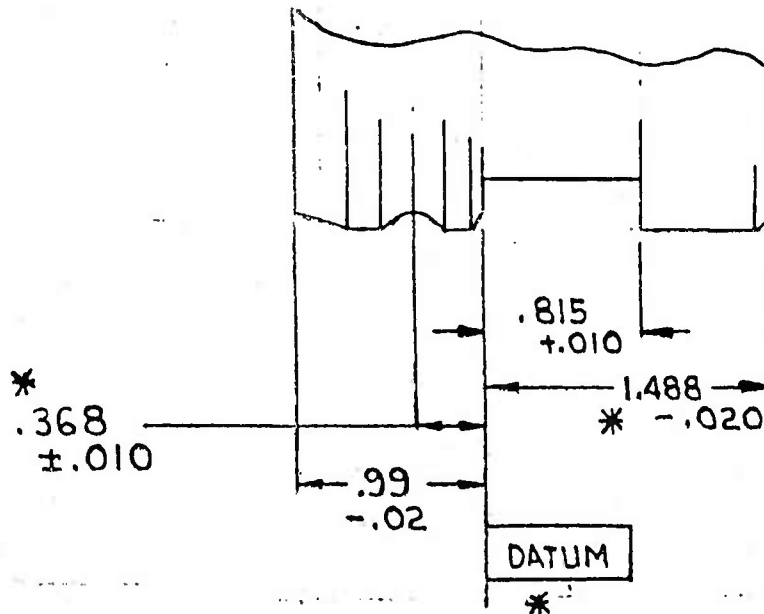


Figure 2. Crimp configuration

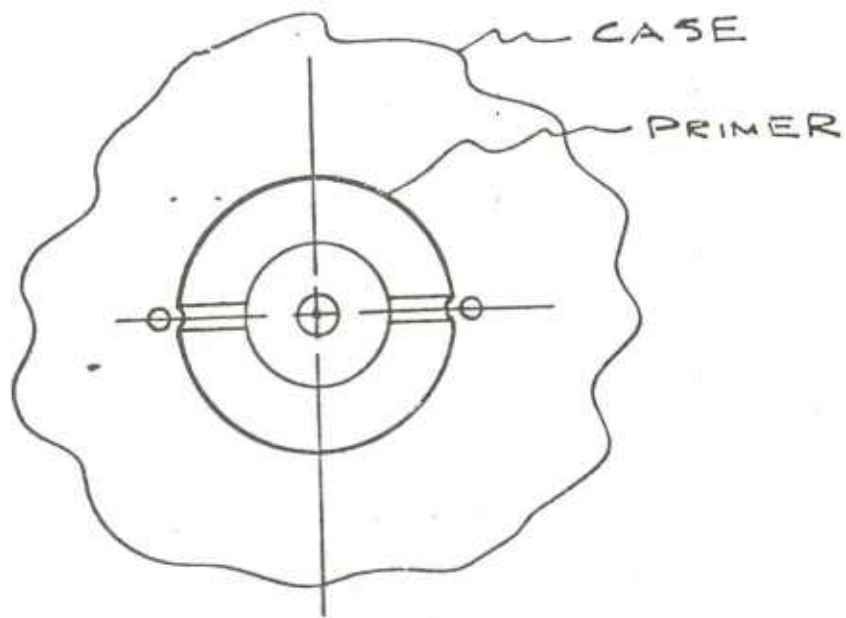


Figure 3. Primer stake

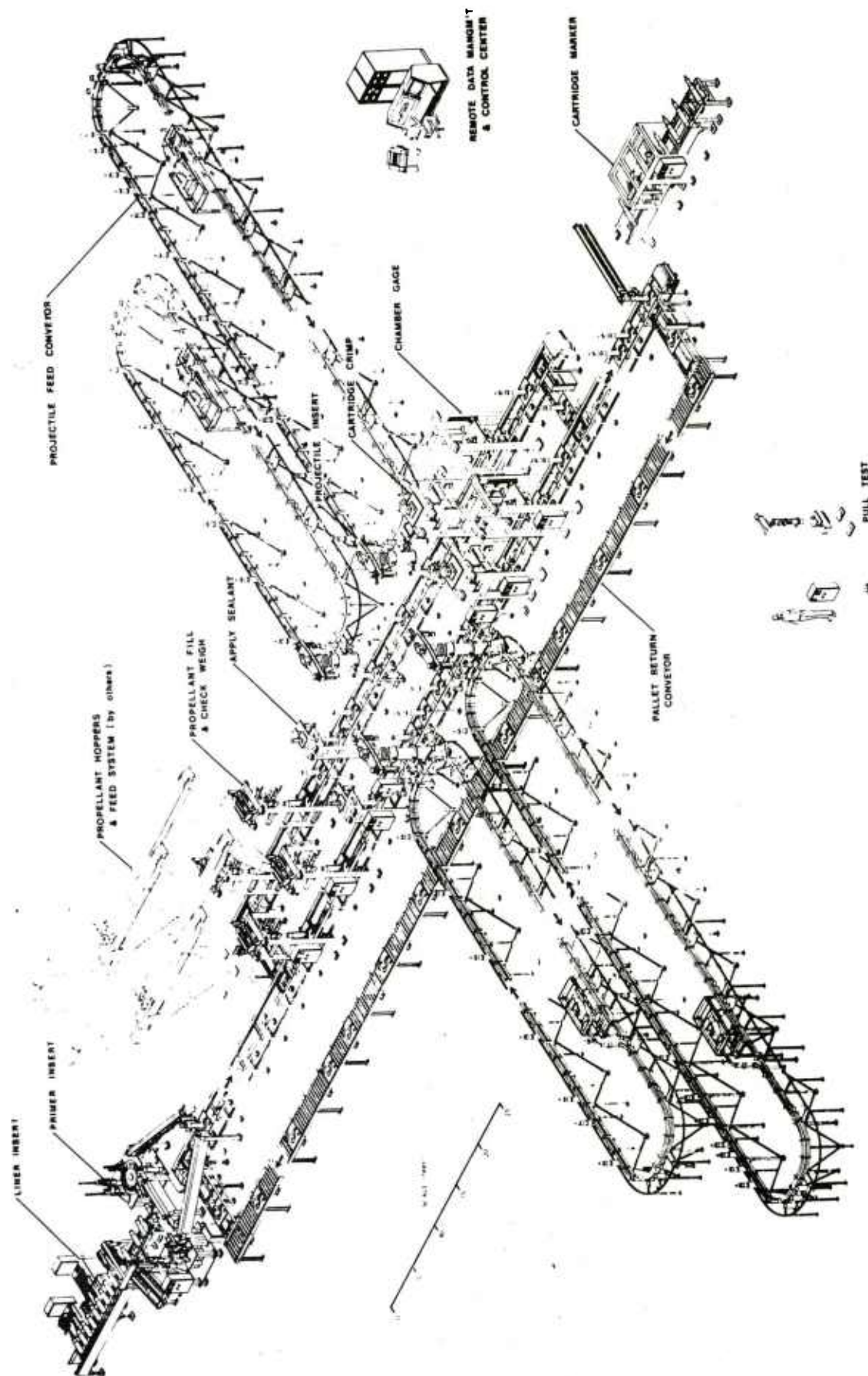


Figure 4. 105-mm tank cartridge load and assembly line

MAINLINE CONVEYOR LOOP TRANSFER LOCATION

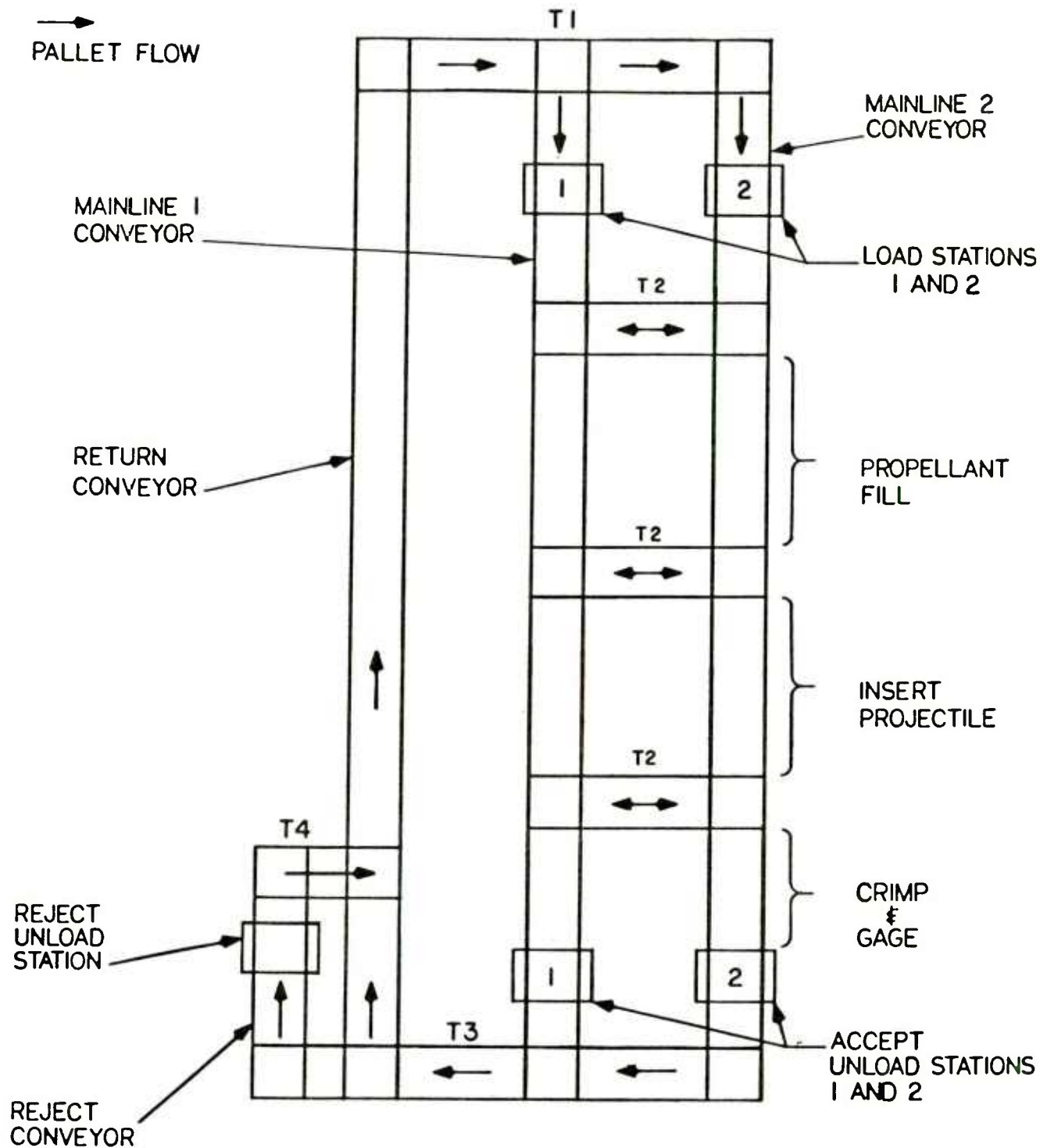
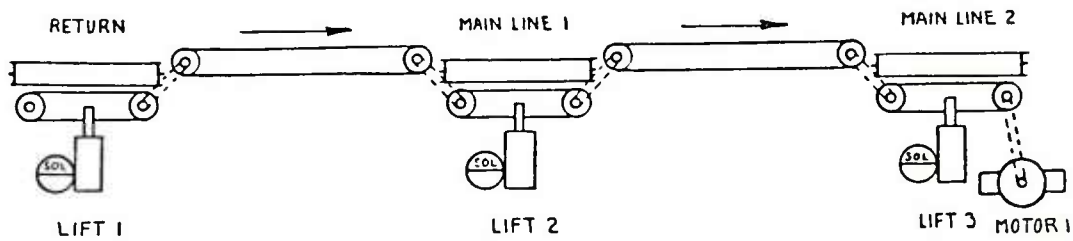
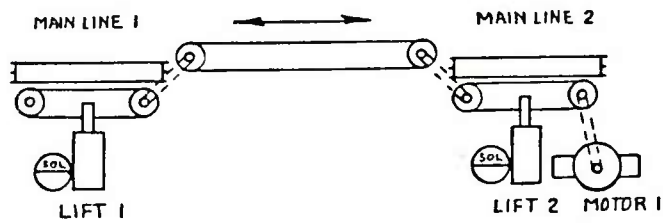


Figure 5. Mainline conveyor loop transfer location

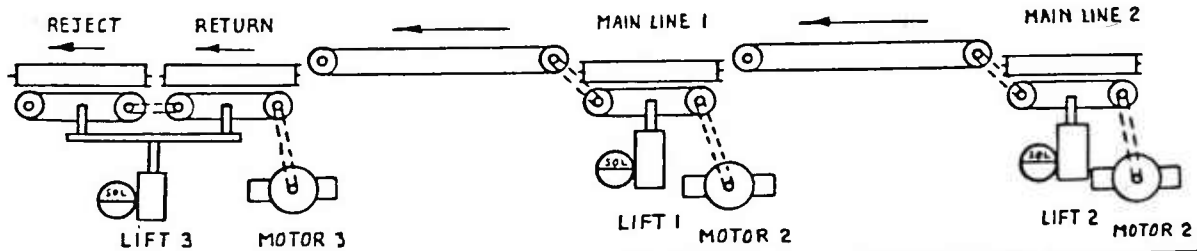
TRANSFER 1



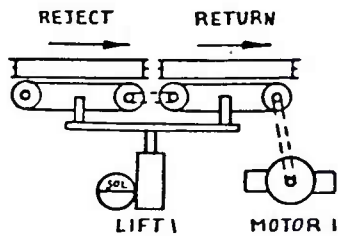
TRANSFER 2



TRANSFER 3



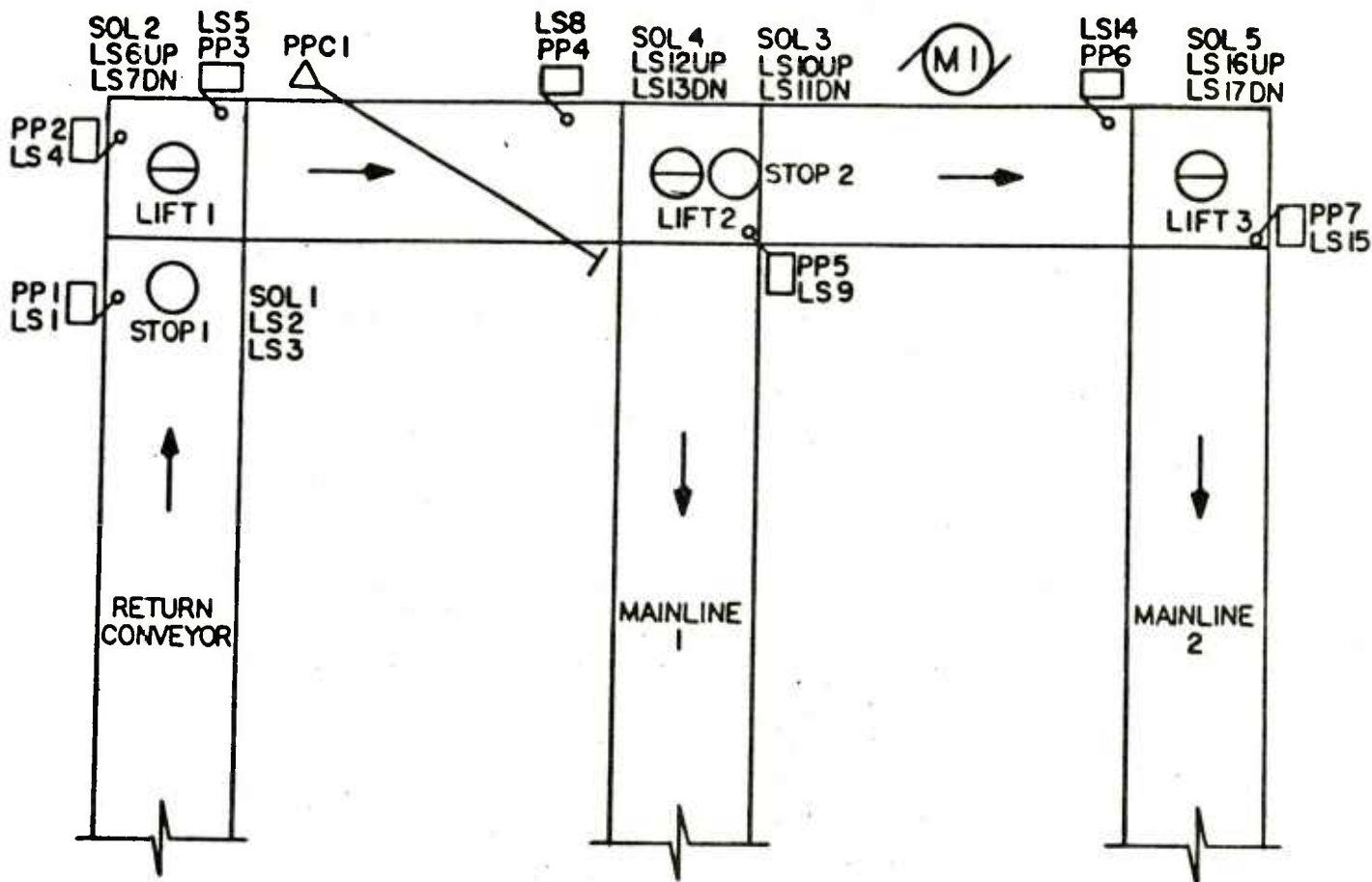
TRANSFER 4



SYMBOLS

- Pallet present at position 1 - limit switch 1
- Pallet stop - solenoid operated - has up and down limit switches
- Transfer lift - detented, solenoid operated, has up and down limit switches
- Clutch/brake - solenoid operated
- Pallet present photocell 1
- Shell present photocell 1
- Code reader - reads "A", "B", and/or "reject" flags on the pallet
- Motor 1

Figure 6. Conveyor types



SYMBOLS

- PP1
LS1 Pallet present at position 1 - limit switch 1
- Pallet stop - solenoid operated - has up and down limit switches
- Transfer lift - detented, solenoid operated, has up and down limit switches
- Clutch/brake - solenoid operated
- PPC1 Pallet present photocell 1
- SPC1 Shell present photocell 1
- CR Code reader - reads "A", "B", and/or "reject" flags on the pallet
- M1 Motor 1

Figure 7. Transfer 1, device layout

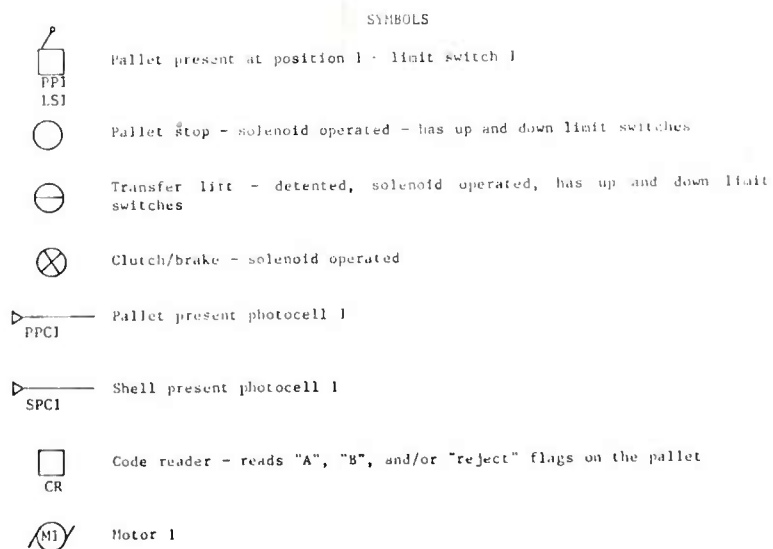
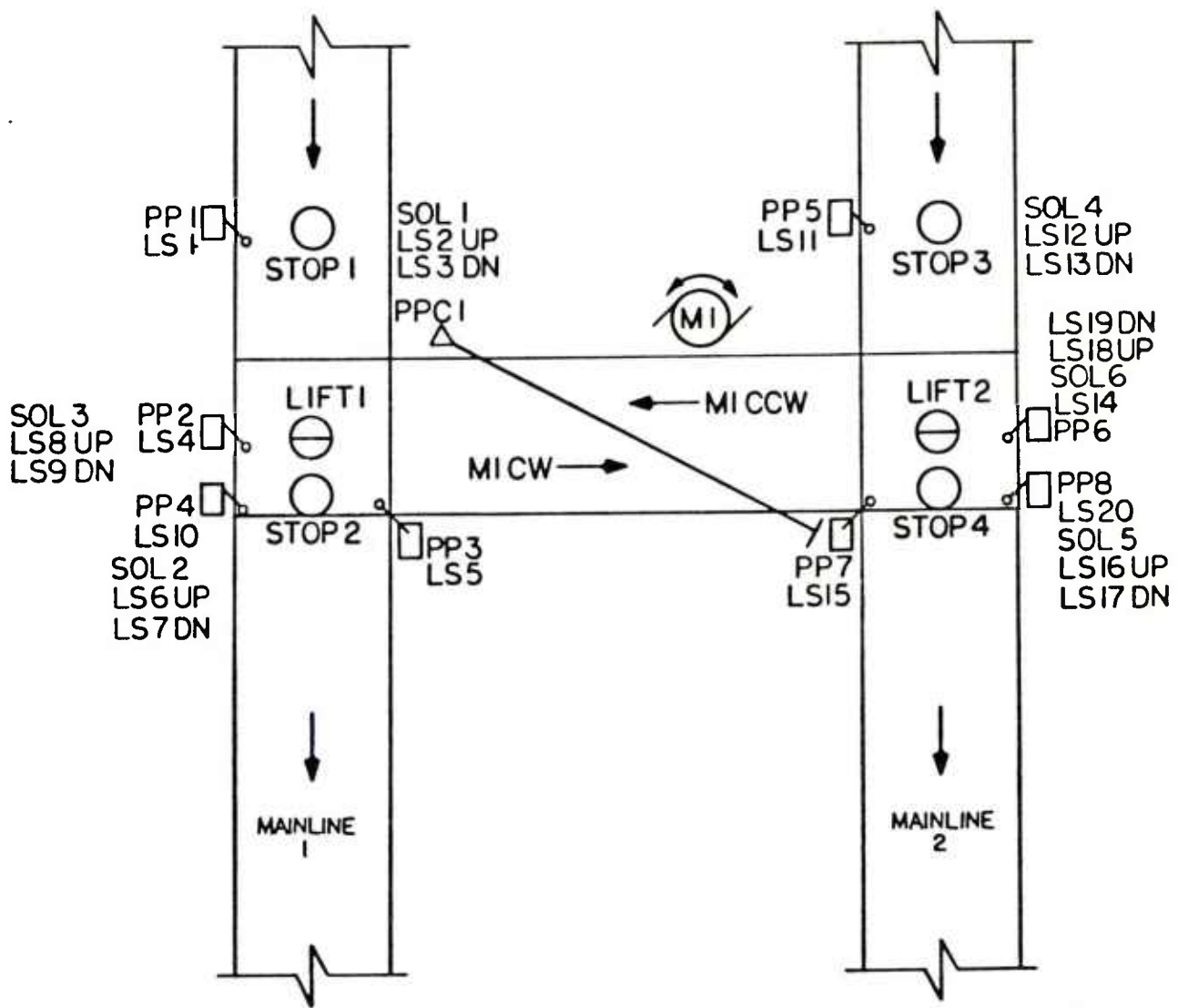


Figure 8. Transfer 2, device layout

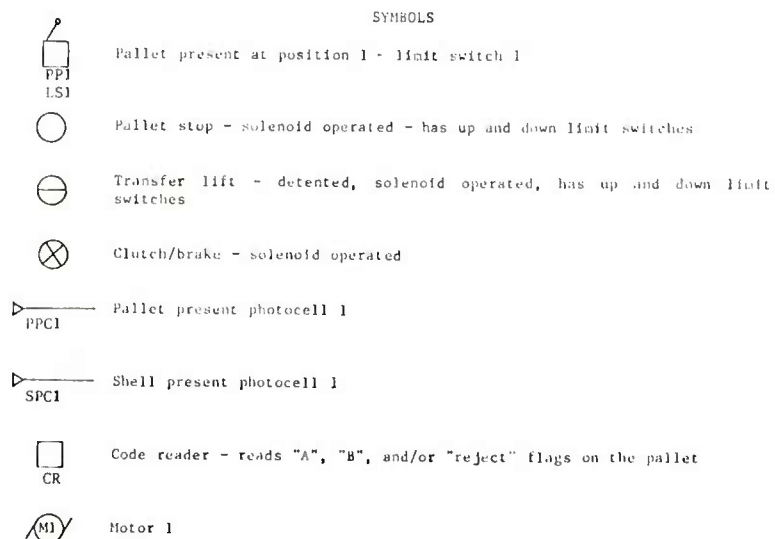
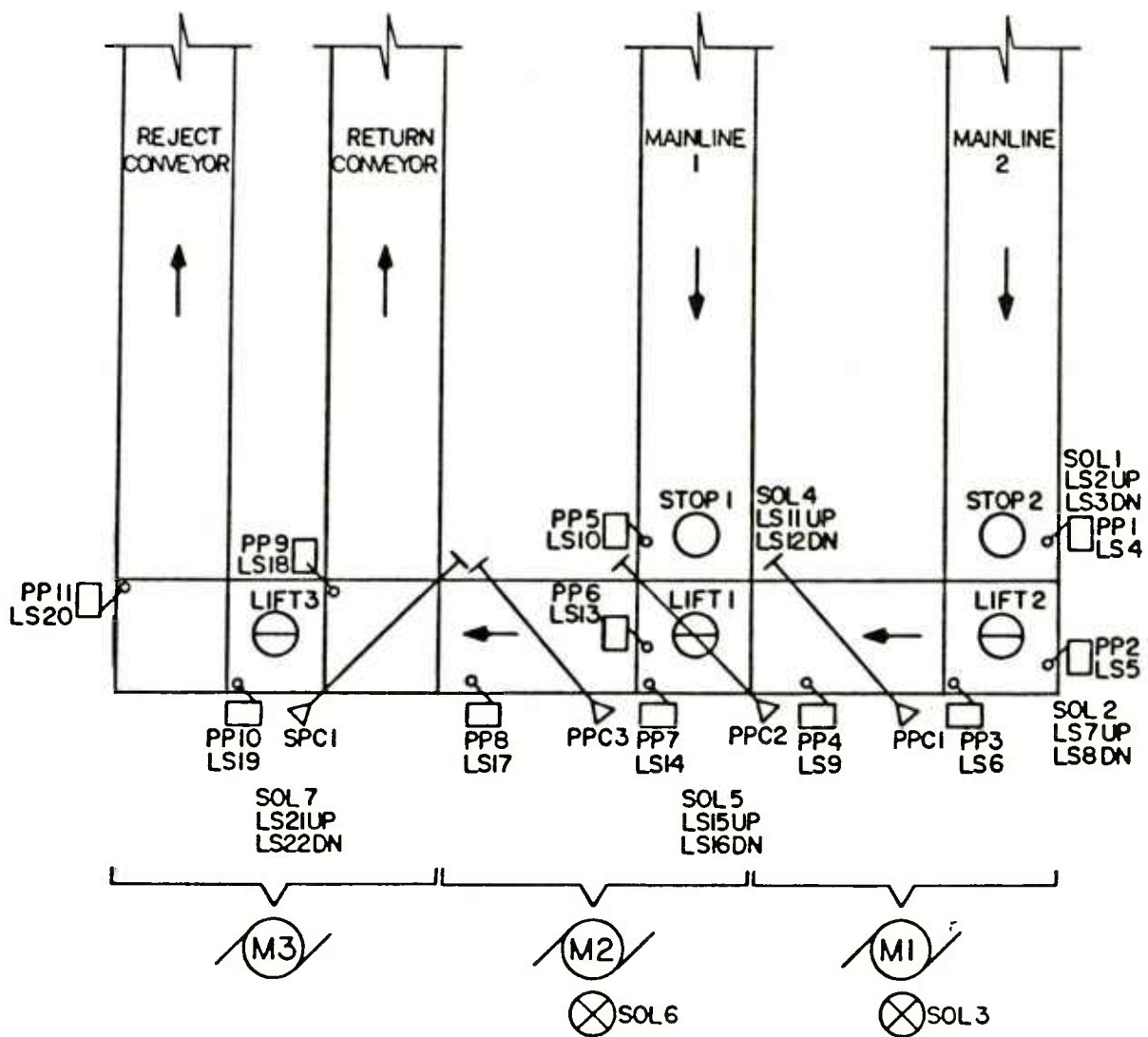


Figure 9. Transfer 3, device layout

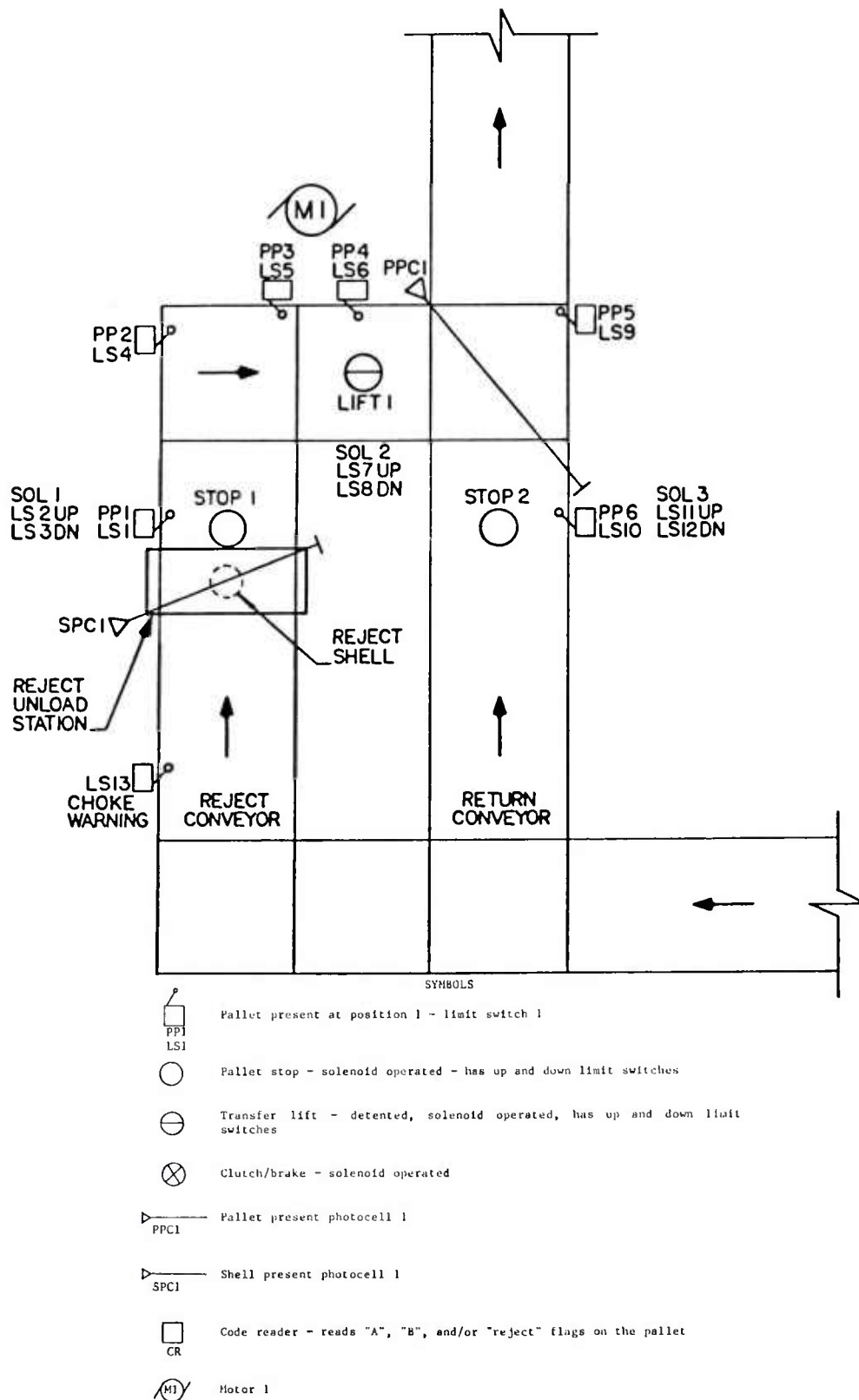


Figure 10. Transfer 4, device layout

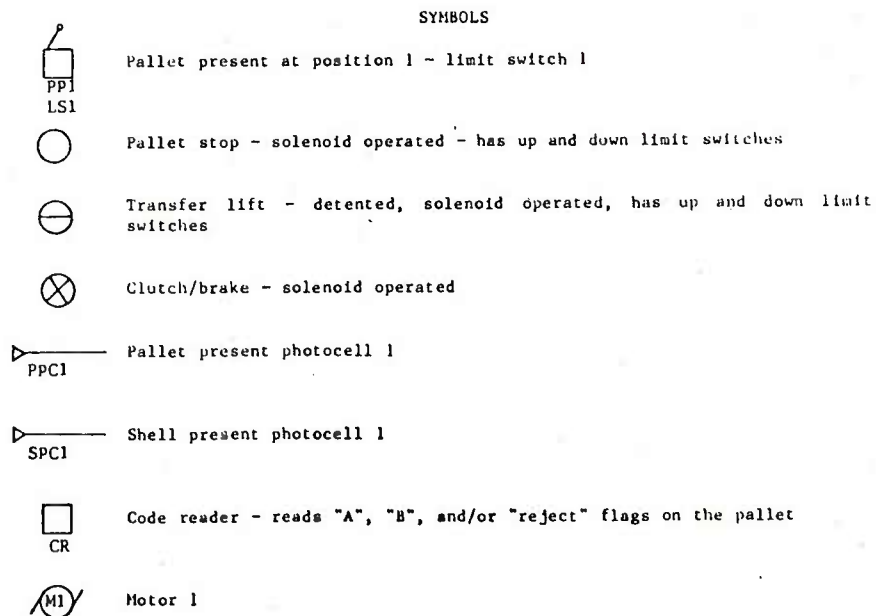
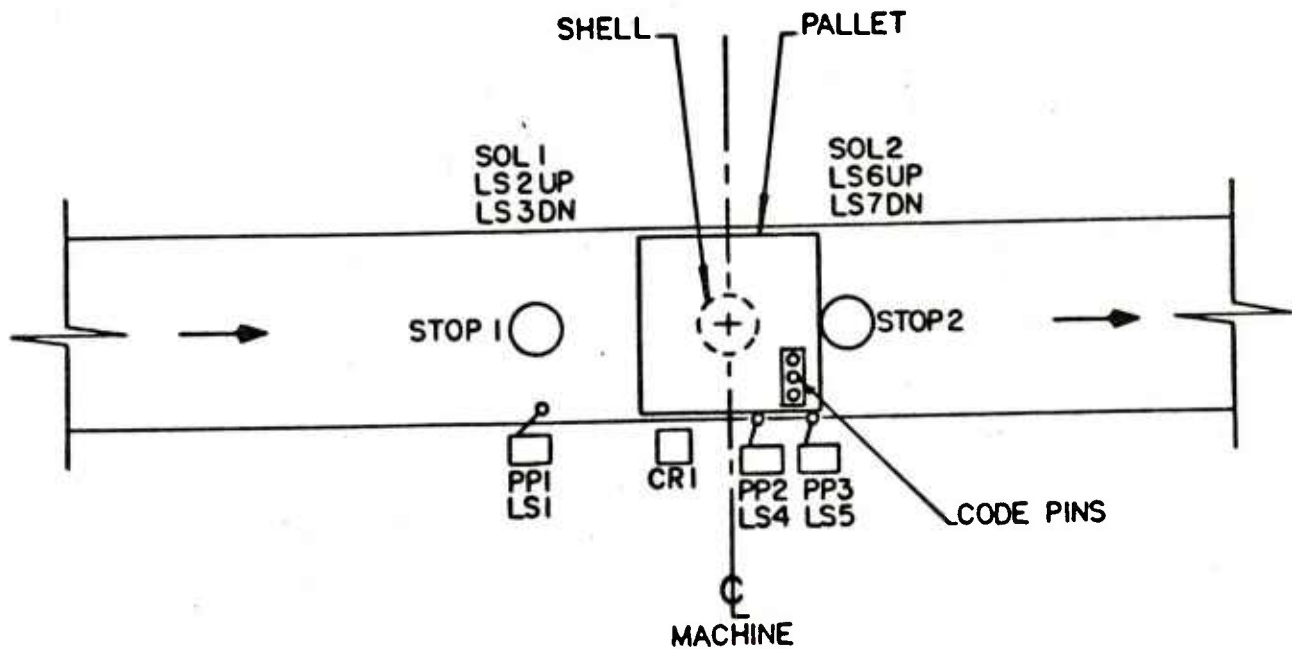
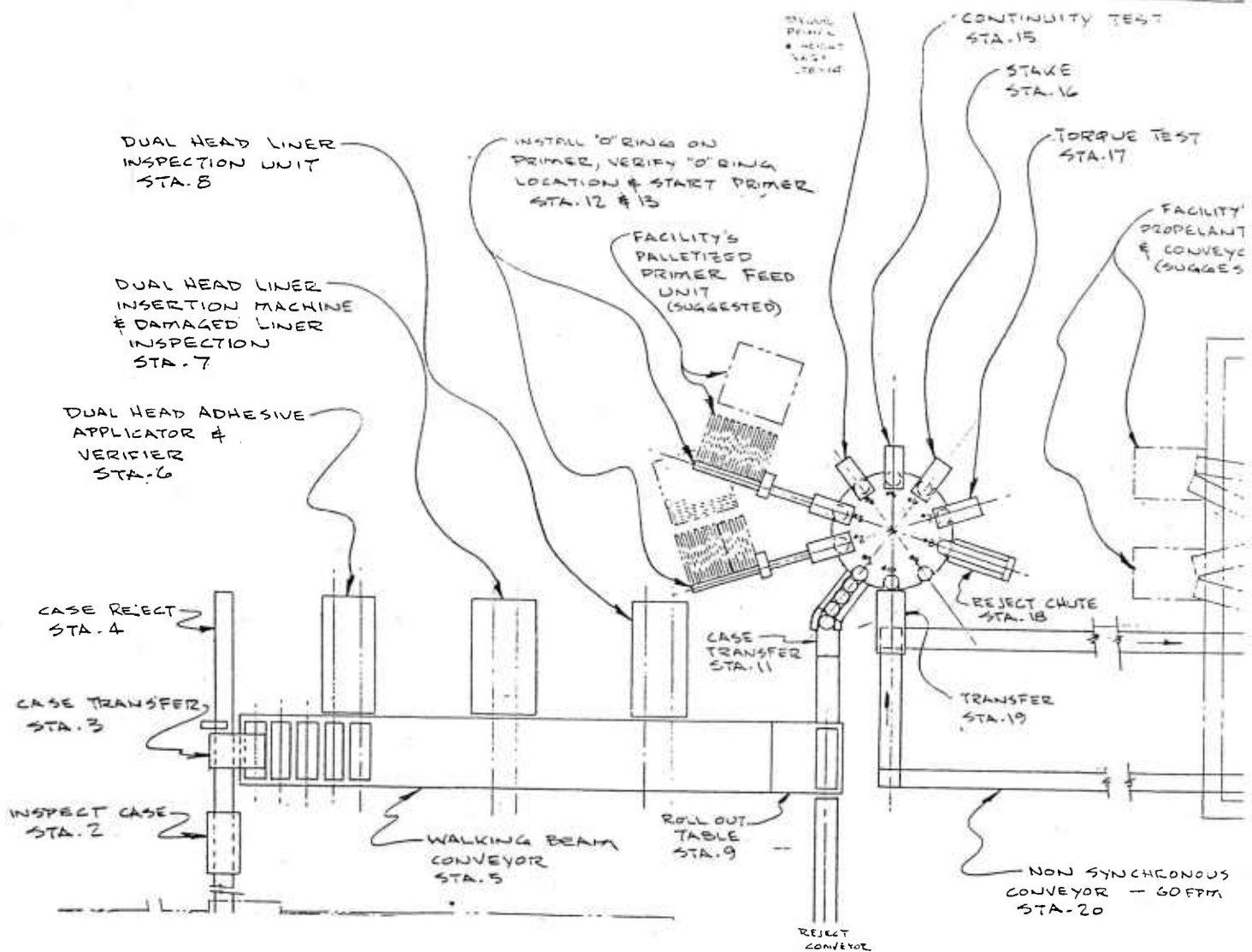


Figure 11. Machine centerline stop



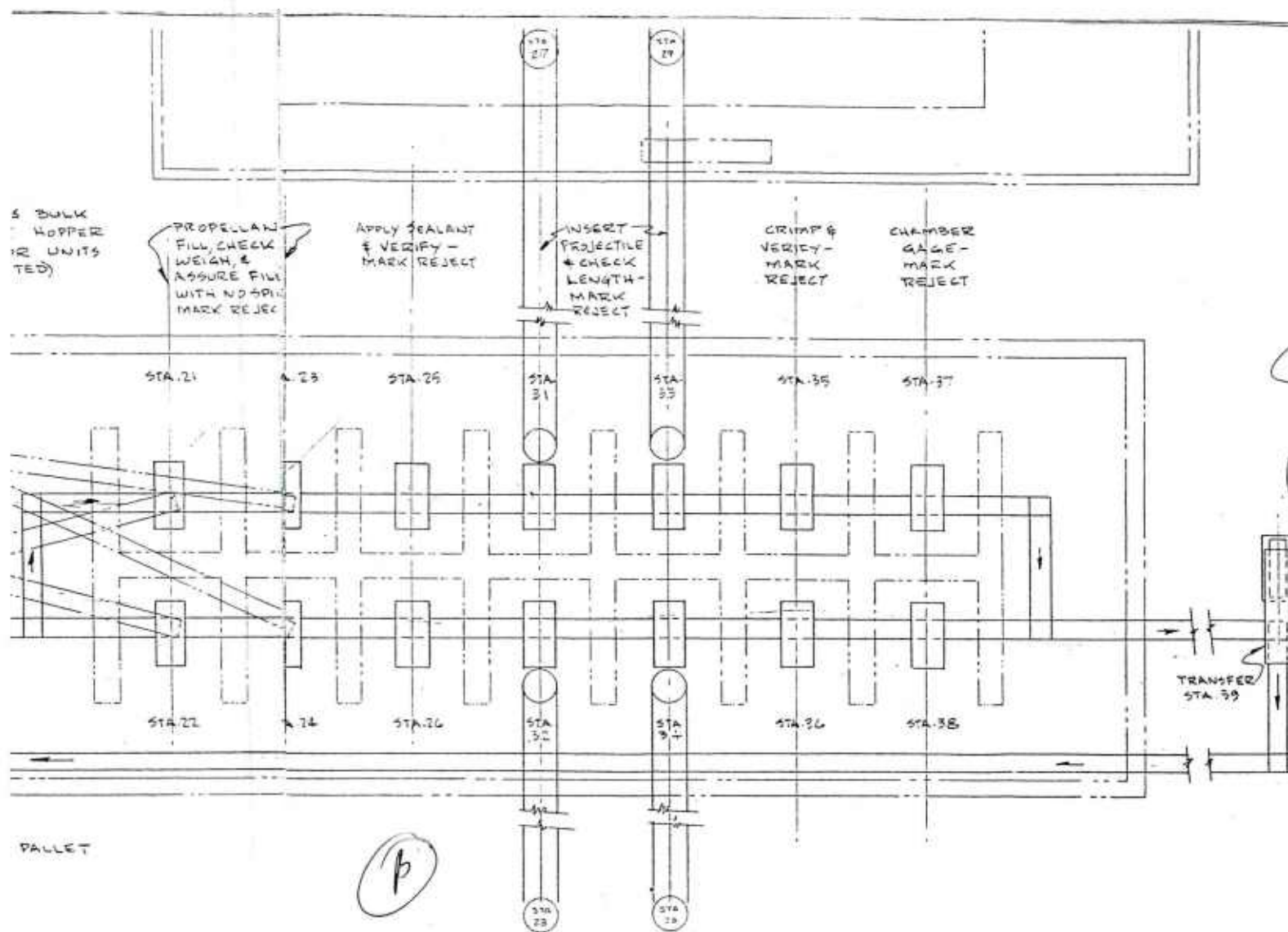
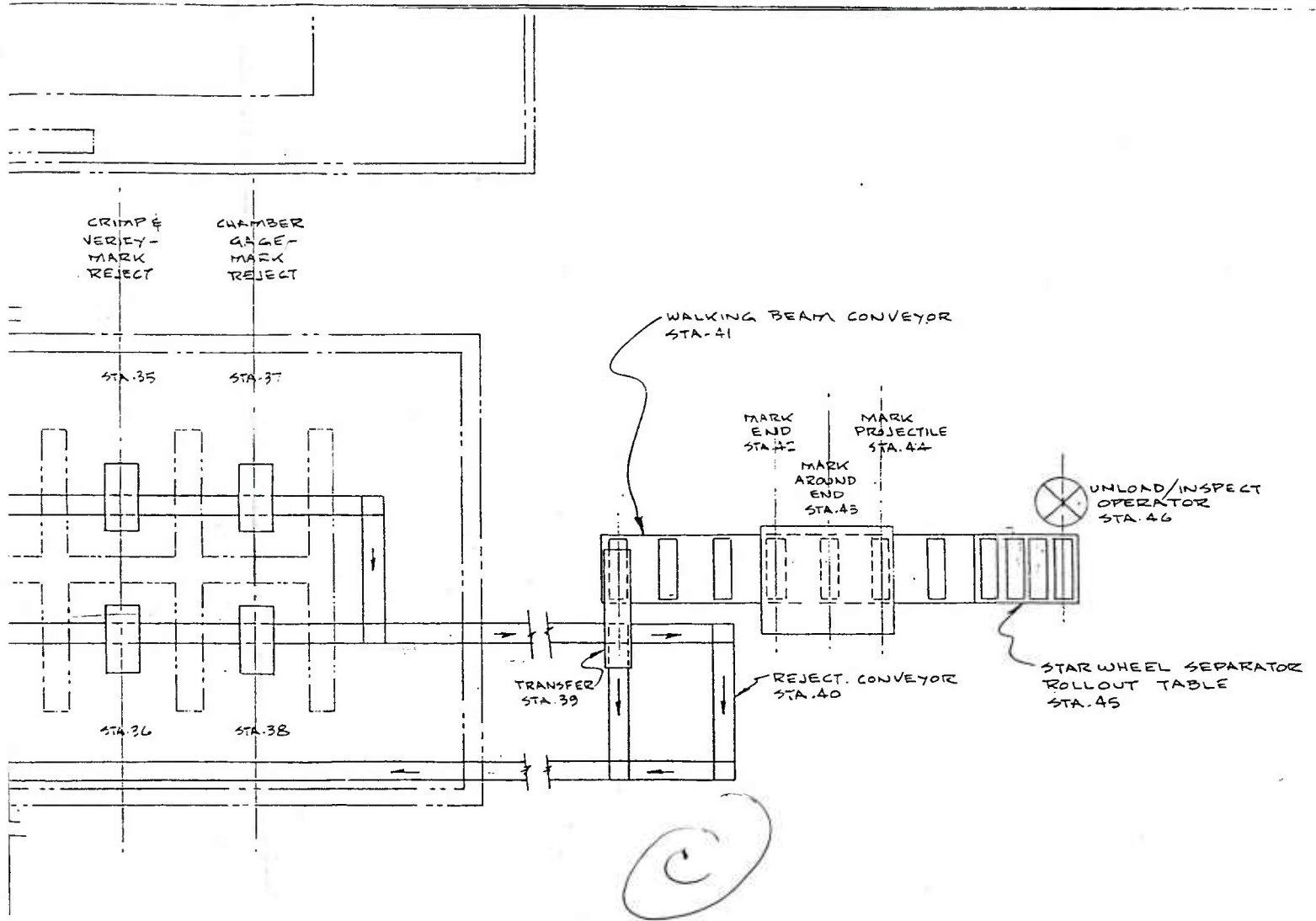


Figure 12. 105-mm assembly line



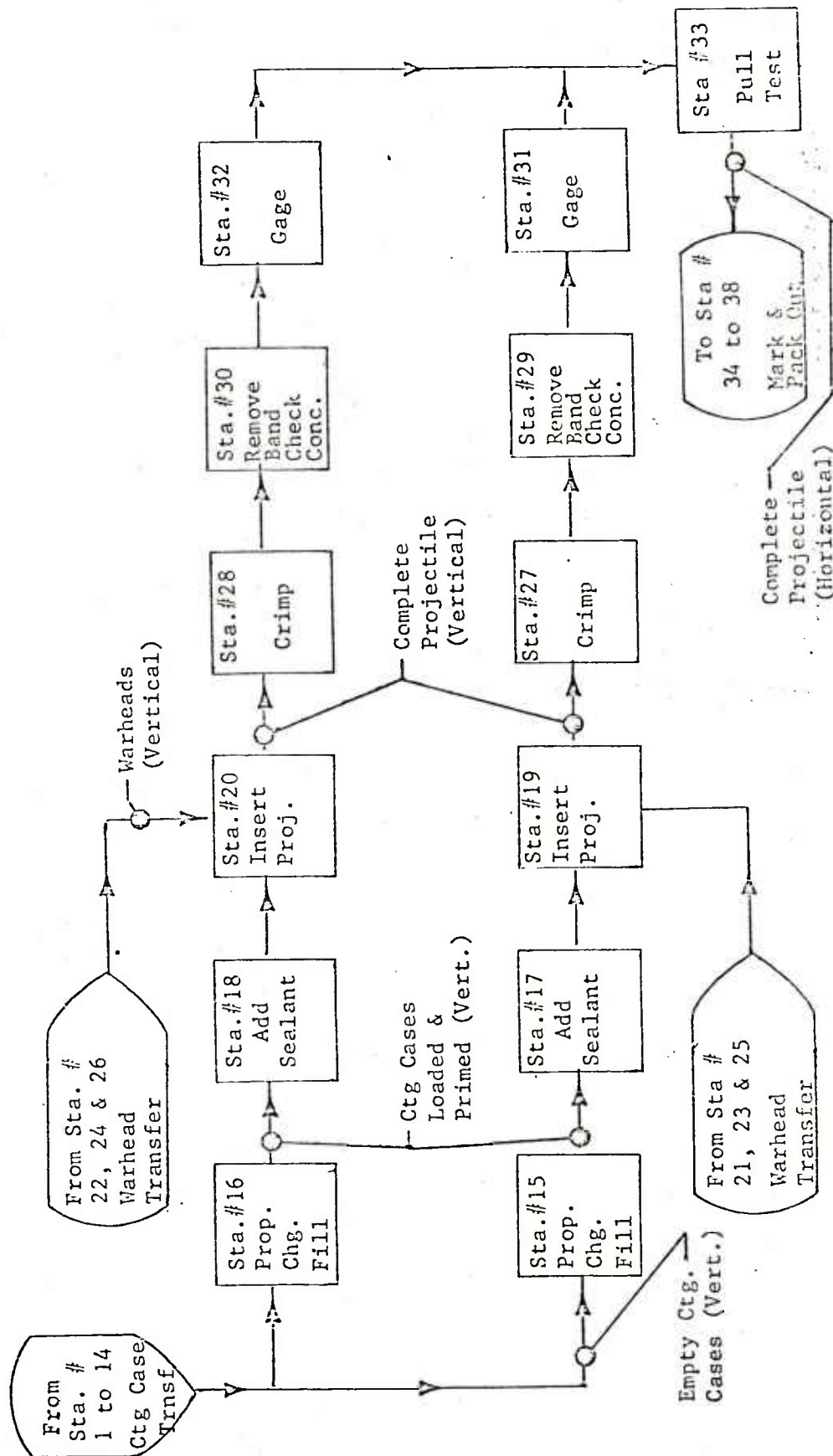
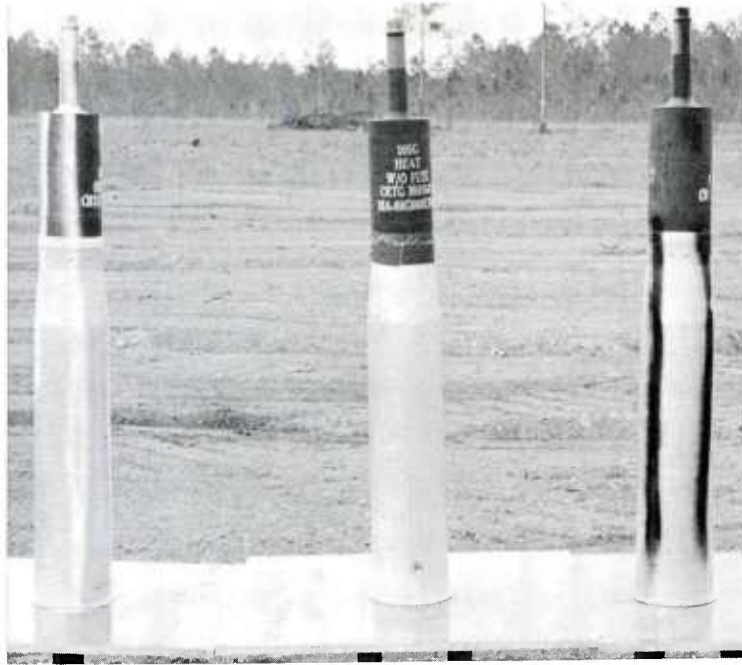
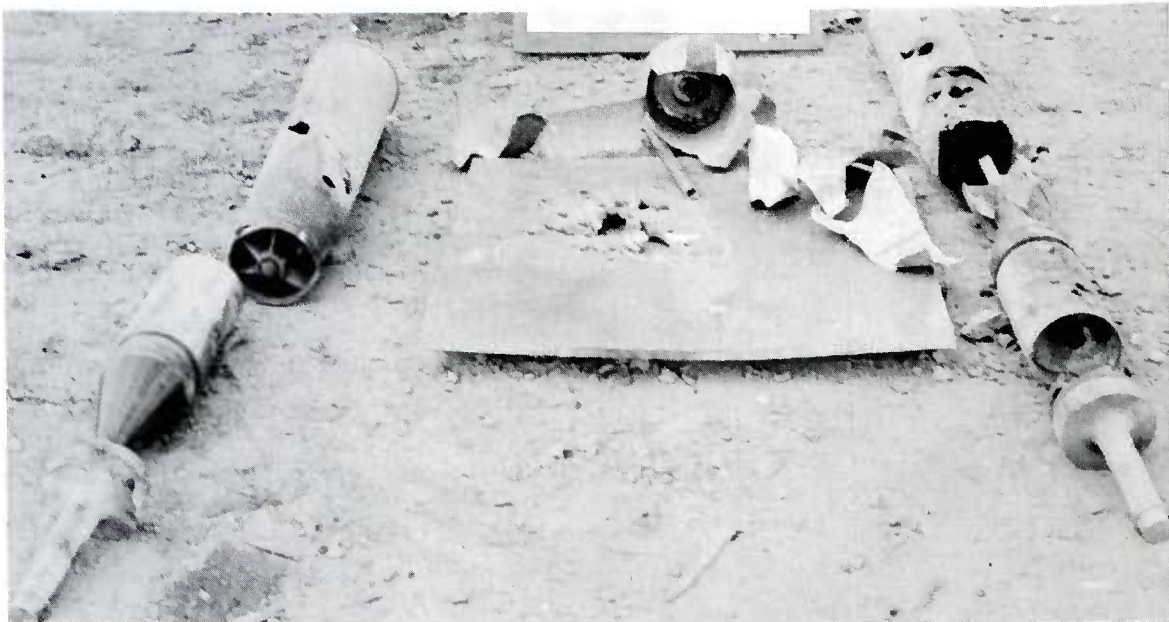


Figure 13. Operational line layout for the M456 HEAT-T projectile assembly line



August 13, 1980, 33 80 CI, phase 2

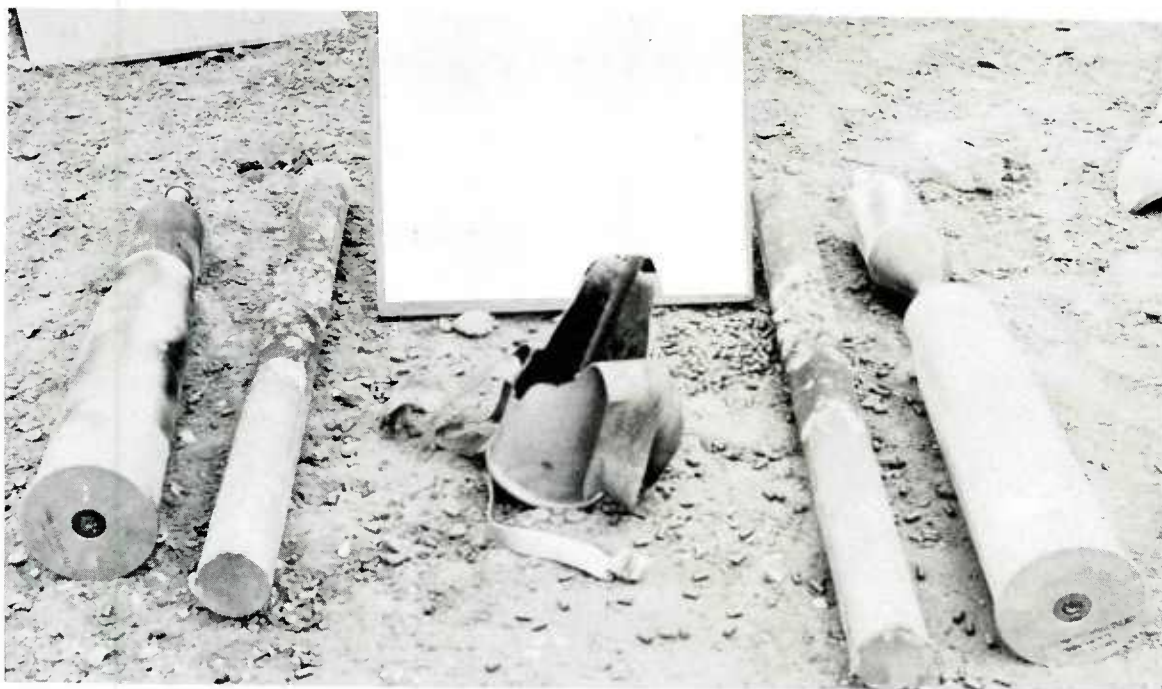


August 14, 1980, 33 80 D2, phase 4

Figure 14. Safe separation tests for 105 mm M456 HEAT-T projectile, unprotected



August 14, 1980, 33 80 C4, phase 3



August 19, 1980, 33 80 C6, phase 3

Figure 15. Safe separation tests for 105-mm M456 HEAT-T projectile, protected

APPENDIX

SAFE SEPARATION DISTANCE TESTS FOR

105-mm M456 HEAT-T PROJECTILE

Objective

To establish safe separation nonpropagating distance criteria between various assembly configurations of the 105 mm M456 HEAT-T projectile under simulated loading plant operational conditions for Milan Army Ammunition Plant (AAP).

Test Plan

The test plan will be divided into four phases in order to simulate four different loading plant operational conditions. These conditions are located as shown on figure A-1.

1. Phase 1 - This phase will simulate LAP facility conditions between stations 15/16 and stations 19/20 on the main dual conveyor system. Cartridge cases with primers and propellants will be vertically positioned on a simulated conveyor containing transfer pallets (fig. A-2), and the safe separation nonpropagation distance determined. A series consisting of 10 exploratory tests to establish the nonpropagating distance and 25 confirmatory tests to statistically confirm the established distance are anticipated. Testing will start at a center-to-center distance of 23 inches.

2. Phase 2 - This phase will simulate LAP facility conditions between stations 23/26 and stations 19/20 on the warhead supply conveyor system. Warheads will be vertically positioned on a simulated conveyor system as shown in figure A-3, and the safe separation nonpropagation distance determined. A series consisting of 10 exploratory tests and 25 confirmatory tests are anticipated in order to establish and statistically confirm the safe distance. Testing will start at a center-to-center distance of 15 inches.

3. Phase 3 - This phase will simulate LAP facility conditions between stations 19/20 and station 34 on the main dual conveyor system. Complete projectiles will be vertically positioned on a simulated conveyor system as shown in figure A-4, and the safe separation nonpropagation distance determined. A series consisting of 10 exploratory tests and 25 confirmatory tests are anticipated in order to establish and statistically conform the safe distance. Testing will start at a center-to-center distance of 23 inches.

4. Phase 4 - This phase will simulate LAP facility conditions between stations 34 and 38 on the walking beam conveyor system. Complete projectiles will be horizontally positioned on a simulated conveyor system as shown in figure A-5 and the safe separation nonpropagation distance determined. A series consisting of 10 exploratory and 25 confirmatory tests are anticipated, starting at an initial separation distance of 12 inches center-to-center.

Documentation

The only required documentation of this test program is an annotated record of all test firings conducted. This record should include, but is not limited to:

1. Pretest: (a) phase number/letter, (b) test number, (c) test component (cartridge, warhead, or projectile), (d) orientation (vertical or horizontal), and (e) test component center to center distance.

2. Post Test: (a) propagation of detonation (yes or no), (b) approximate separation distances (donor detonation point to acceptor projectiles, and (c) acceptor and pallet (if used) damages.

Pre and post test photographic coverage (stills) will be necessary of all tests.

Materials

ARRADCOM will supply sufficient live cartridge cases, warheads, and projectiles as necessary in order to conduct the full exploratory and confirmatory segments of all four phases of the test program. The following test quantities assume only 10 exploratory tests are necessary to establish a safe separation distance and that acceptor units are reusable from test to test:

1. Cartridge cases with propellant and primer - 66
2. Warheads - 30
3. Warheads with electric detonators - 36
4. Complete projectiles - 60
5. Complete projectiles with electric detonators - 72

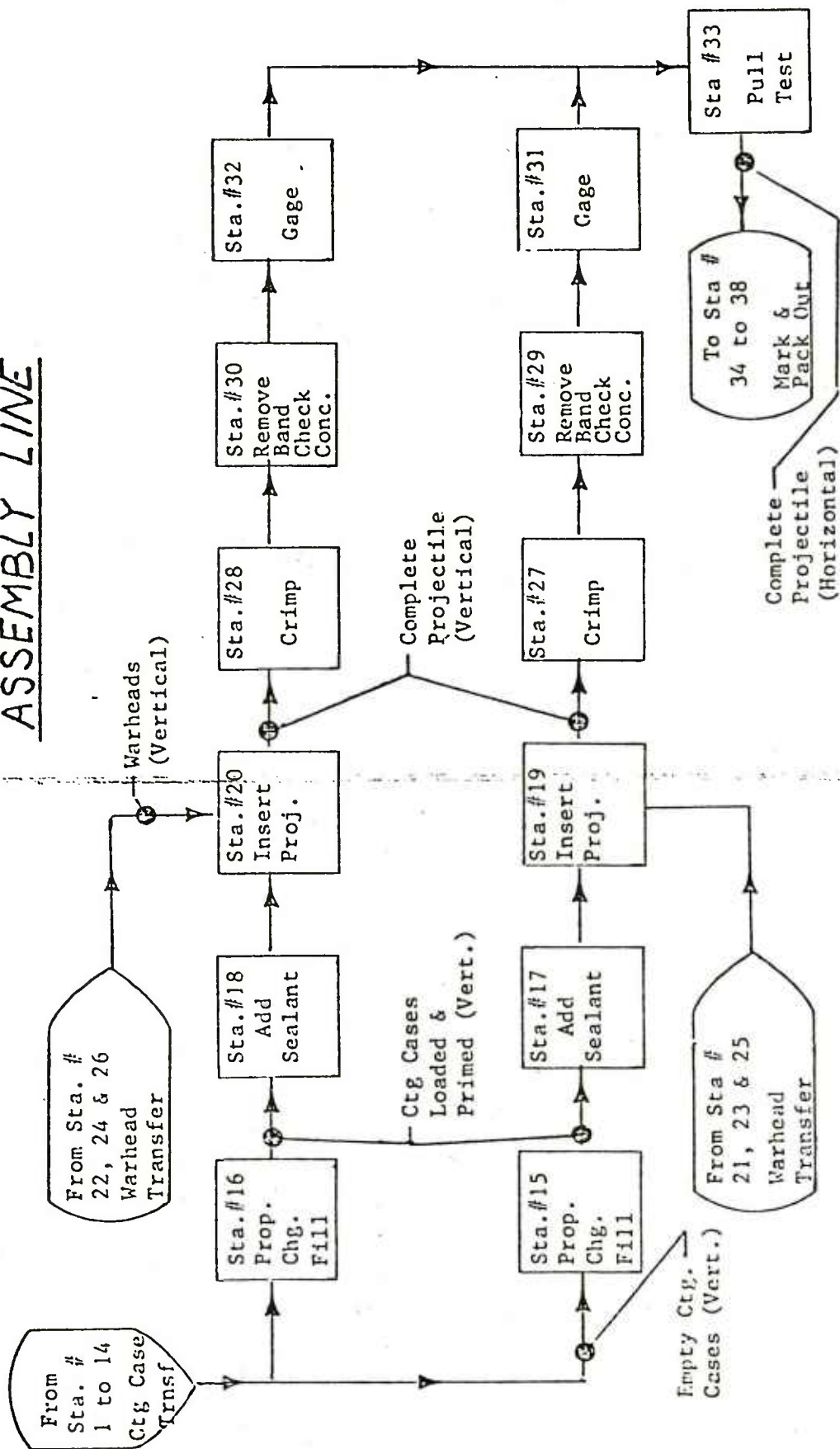
The testing agency will furnish: (a) the necessary remote site, (b) sufficient test personnel, (c) simulated pallets and conveyor systems, (d) donor initiation system (phase 1 only), and (e) photographic coverage materials. The testing agency will also supply those materials necessary for post test cleanup, area decontamination, and disposal of excess materials.

Safety Precautions

The usual safety precautions on handling and testing of explosives should be observed. It should be noted that this projectile's warhead has a setback arming fuze with a piezoelectric functioning element; therefore, warheads with penetrations near the fuze element (obturator area) should be handled as armed munitions and disposed of according to standard procedures.

105MM M456 HEAT-T PROJECTILE

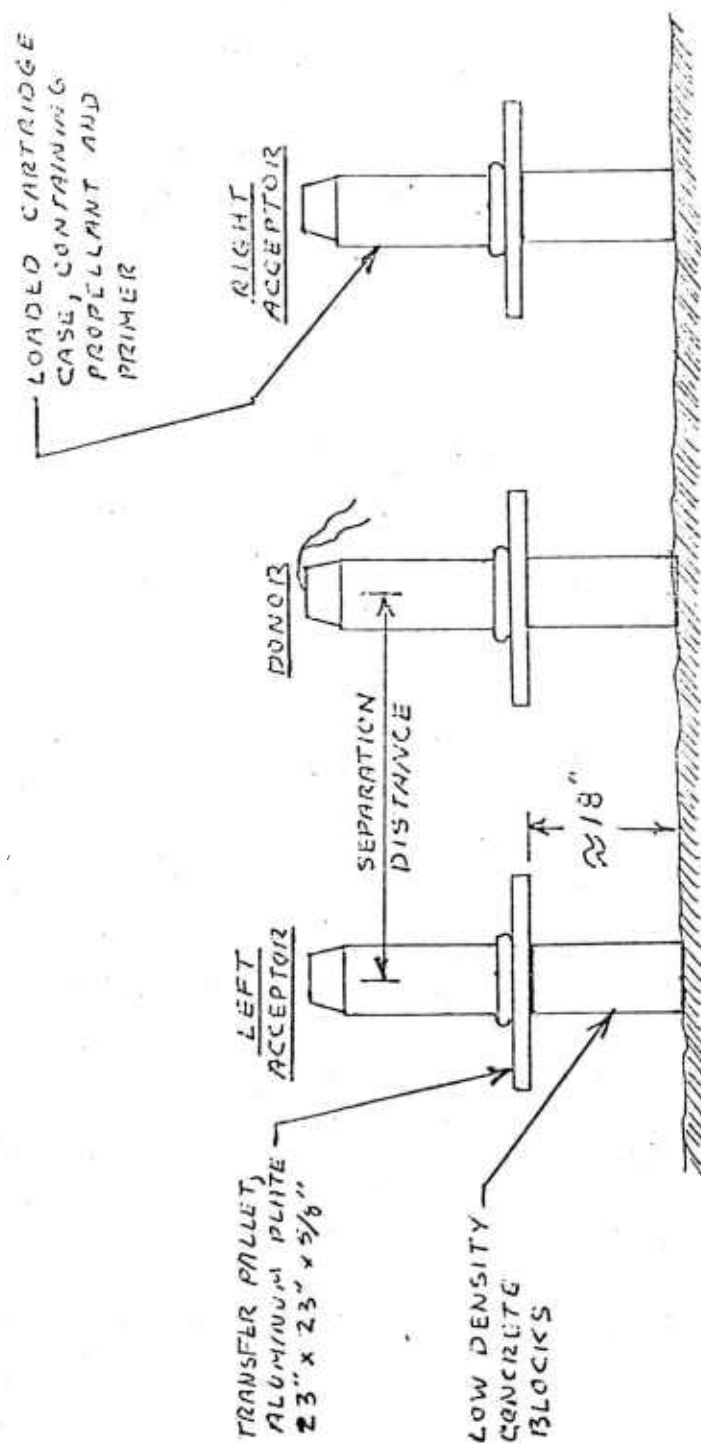
ASSEMBLY LINE



WMS JAN 80

Figure A-1.

105MM M456 HEAT-T PROJECTILE LOADED CARTRIDGE CASE TEST (PHASE I)

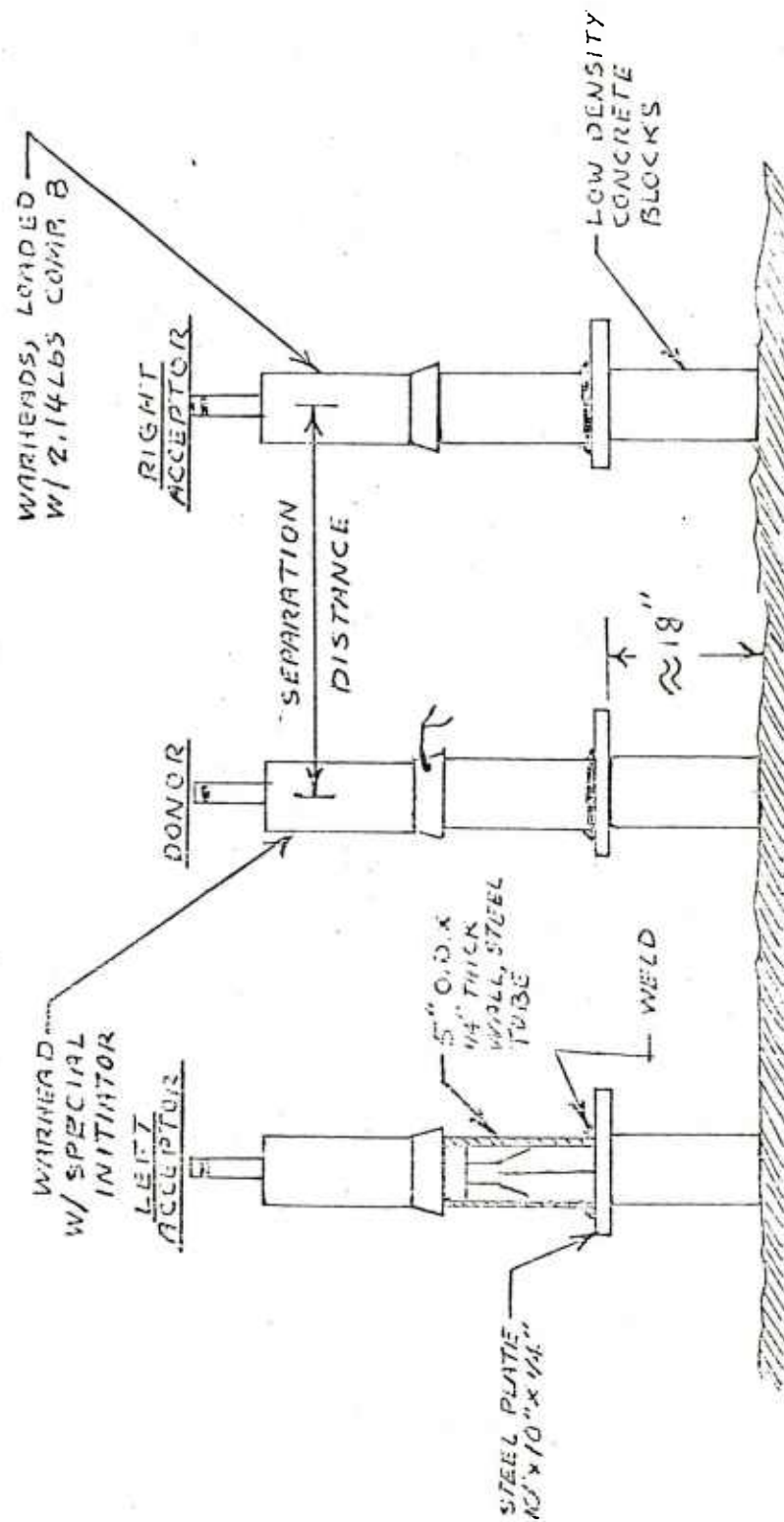


WVS FEB '80

Figure A-2

105mm M456 HEAT-T PROJECTILE

WARHEAD TEST
(PHASE 2)



MS. A.9.2.90

Figure A-3

105MM M456 HEAT-T PROJECTILE PROJECTILE TEST

(PHASE 3)

VERTICAL TEST

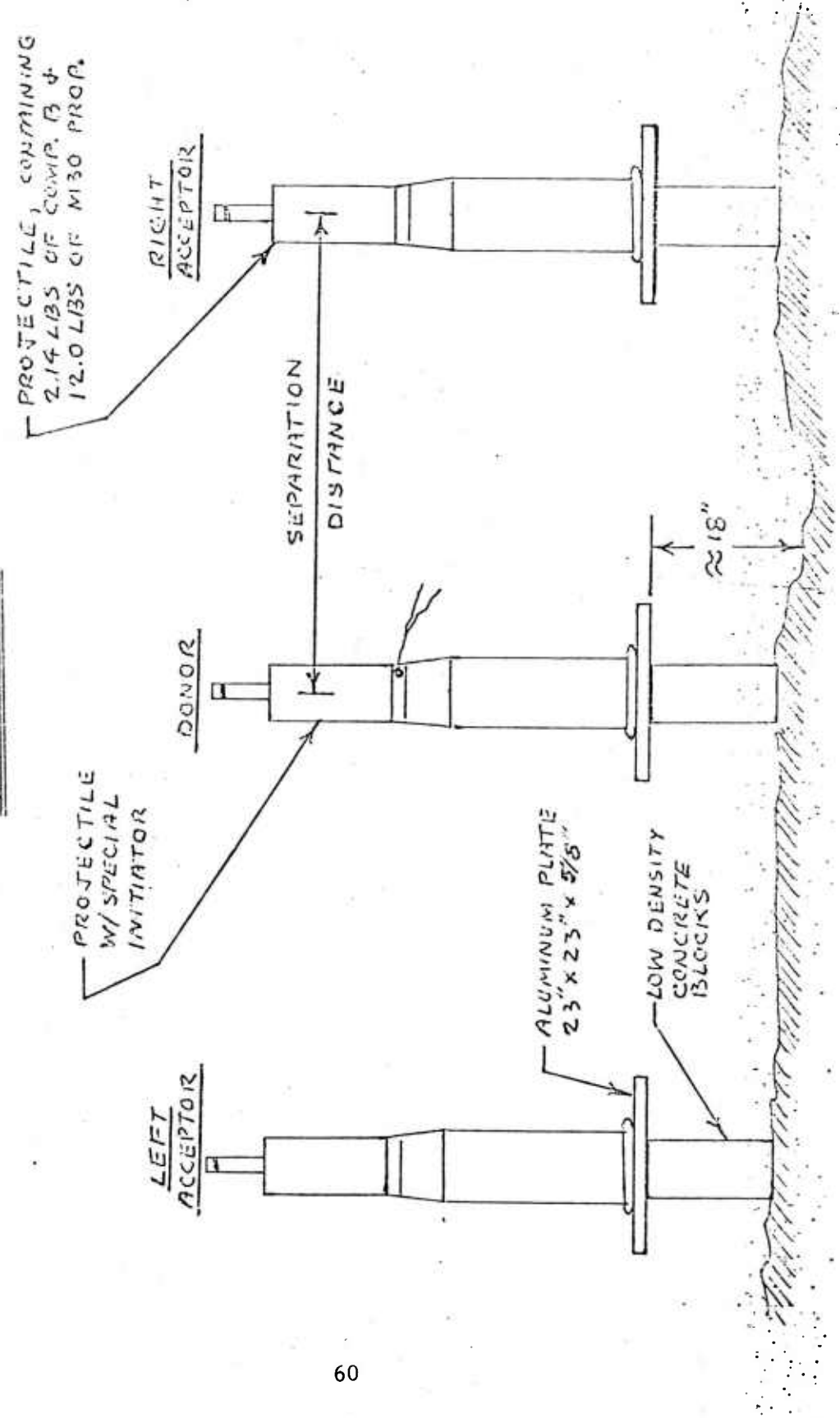


Figure A-4

WMS 1000'80

105MM M456 HEAT-T PROJECTILE

PROJECTILE TEST

(PHASE 4)

HORIZONTAL TEST

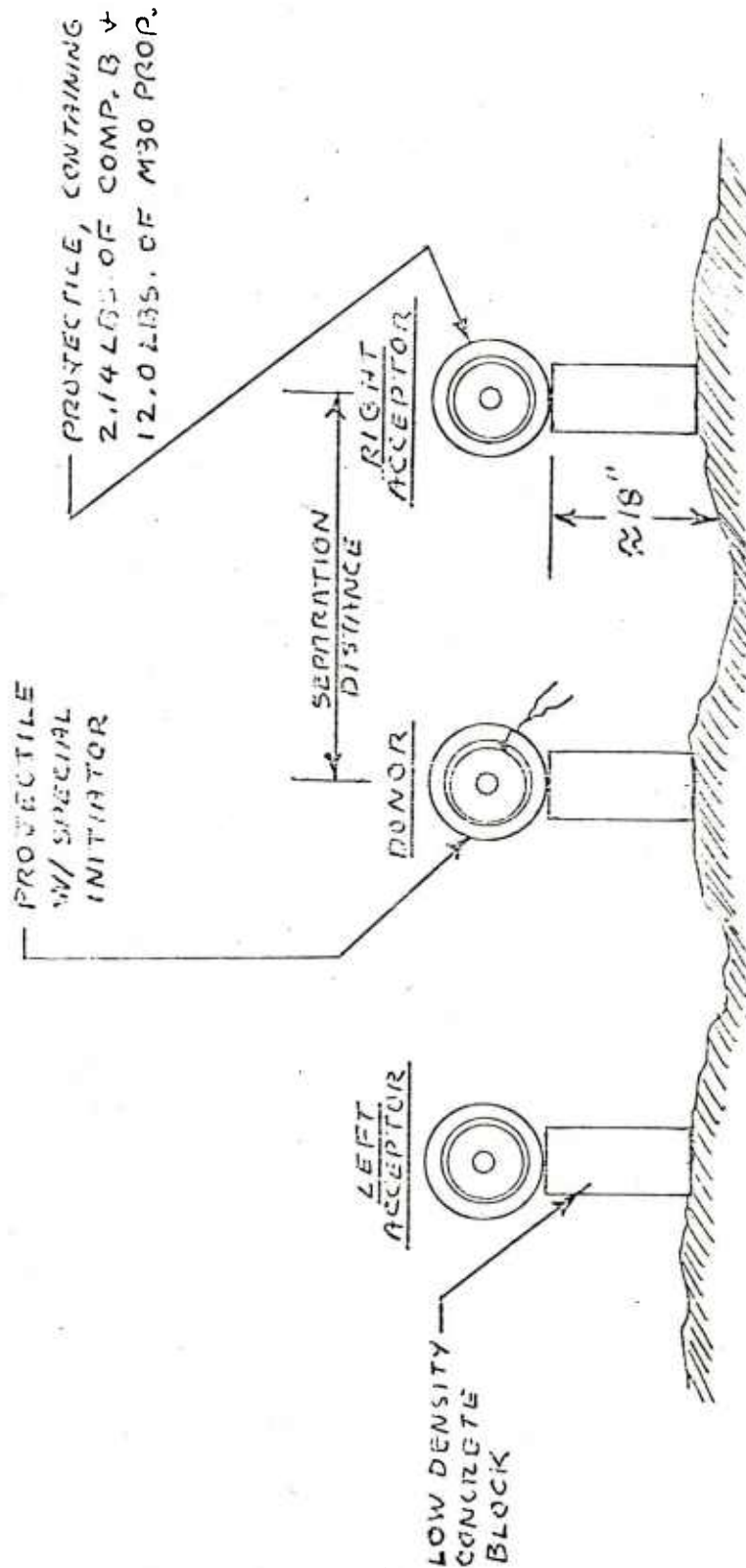


Figure A-5

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